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Mitigating the Risks in Energy Retrofits of Residential Buildings in China

Dissertation

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chair of the Board for Doctorates
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Tuesday, 14 December 2021 at 15.00 o'clock

by

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Summary

Since 1978, the real estate industry has formed and developed rapidly in China. A large number of residential buildings were built to meet people's needs, especially in the 1980s and 1990s in China, but the quality and performance of these buildings were ignored due to the lack of laws, regulations, and standards. More than 70% of buildings in China are those with high energy consumption, especially in the Hot Summer and Cold Winter (HSCW) zone, where more than half of urban residential buildings were built without any thermal insulation measures (Fu, 2002). However, compared with the huge stock of the buildings with high energy consumption, the renovations for energy-saving that have been completed are far from enough, especially in the HSCW zone (MOHURD, 2017). To achieve the climate target, it is necessary to accelerate the implementation of residential energy retrofitting in the HSCW zone of China. Nevertheless, homeowners are generally unwilling to make major changes to their homes (e.g. the renovation of the building envelope) in China (Baldwin et al., 2018), even if they can benefit from energy retrofitting, like the improvement of building quality and living comfort. This unwillingness can be attributed to the existence of risks and their negative impacts on project performance in quality, time, costs, etc. Indeed, the retrofitting projects are vulnerable to the problems of cost overruns, poor quality, project delay, etc. (Hwang et al., 2015; Liu et al., 2020), which would damage homeowners' interests. Thus, the risk is an important factor hindering these project objectives and project success (Zou et al., 2007). Residential energy retrofitting in the Chinese context is featured by uncertainties, posing various risks about homeowner attitudes and behaviours, stakeholder coordination, the quality of design and construction, etc. This thesis aims to deepen the understanding of risks in the whole process of residential energy retrofitting to smoothen its implementation and develop risk mitigation strategies for the HSCW climate zone of China. It answers the following main research question: What are the risks hindering the implementation of residential energy retrofitting projects in the HSCW zone of China, and what strategies can mitigate these risks?

This research study adopts the risk management process as a conceptual framework for exploring the strategies of risk mitigation in energy retrofitting of residential buildings in the HSCW zone of China. This process includes risk identification, risk assessment, and risk mitigation. Transaction Costs Theory (TCT) is incorporated into this framework, contributing to risk identification and mitigation. Project stages and stakeholders are taken into consideration to identify the risks in the whole process

of energy retrofitting projects systematically. This study assesses the importance of these identified risks in both objective and subjective aspects. The objective assessment considers two parameters of risk probability and impact, while subjective assessment measures the risk perception of different stakeholders. Mitigation strategies are explored from the perspective of stakeholder behaviours to reduce the occurrence of key risks identified from both objective and subjective assessments. Given the importance of homeowners-related risks and the key role of the government in retrofitting projects, homeowners and the government are considered as the main viewpoints for developing mitigation strategies. Anhui province is a representative province of residential energy retrofitting in the HSCW zone, and thus was selected as the case area for data collection in the thesis.

This thesis first explored the key risks hindering the implementation of residential energy retrofitting projects from the perspective of objective risk assessment. A list of energy retrofitting risks with TCs considerations was identified through literature review and semi-structured interviews with key stakeholders in case projects. The questionnaire surveys with professional practitioners were conducted to measure the probability and severity of each identified risk. All risks were ranked in order of importance by combing two methods of risk matrix and Borda voting. The results reveal that ten top risks representing key risks are mostly associated with homeowners and contractors as well as occurring during the stage of on-site construction. Three of the four top risks impeding project implementation are associated with homeowners, starting from their low awareness at the early stage and poor cooperation and opportunistic behaviours during the on-site construction. In terms of risks, and except for the homeowners, the contractors are the most critical stakeholders in on-site construction. Their professional expertise, construction management, and safety management are the essential sources of project risks. In particular, the importance of the risk related to contractors' competence comes from its severe impacts instead of the occurrence probability. The results also show that information, negotiation, and monitoring costs are the main sources of TCs related to ten key risks. Information costs are the most common costs, and government and homeowners are the main bearers. These costs are incurred not only by the government's activities of selecting retrofit projects, technical standards, and technical staff but also by homeowners' behaviours of collecting information on retrofit merits, the reliability of the construction company, and maintenance. Negotiation costs are associated with homeowner-related risks and arise from persuading homeowners at the early stage and renegotiating for homeowners' requirements beyond the plan during the on-site construction. Monitoring costs are related to the maintenance risk and incurred by monitoring energy-efficient technologies and building maintenance after retrofitting.

To explore the risks in-depth, this thesis analyses the risk perception of different stakeholders, which is also a subjective assessment of risks. Based on the risk list identified through literature review and interviews as mentioned above, this study conducted questionnaire surveys to explore the risk perception of four stakeholder groups, namely the government, homeowners, designers, and contractors, by measuring the level of their concern about each risk. Interviews with key stakeholders in case projects were also used to probe stakeholders' proactive behaviours for mitigating all risks. This study reveals that risk perception is diverse among different stakeholders due to their tendency towards responsibility and interests. As the organizer and decision-maker, the government has more concern about the risks affecting the overall enforceability of retrofit projects. Risk perception of designers and contractors is also consistent with their roles as service providers, focusing on the risks hindering the fulfilment of their duties, such as insufficient objective information and uncooperative partners. By contrast, homeowners pay more attention to the risks regarding their own interests, such as the quality of materials, the competence of contractors, contractors' work performance, and the safety of the construction site. In particular, in terms of some construction-related risks (e.g., contractors' abilities, material quality, and the legalization of contractors' actions), homeowners have significantly higher levels of perception than other stakeholder groups. The government selects contractors through bidding, and tends to believe that contractors take the government-investment projects more seriously. The current energy-efficient technologies adopted in most residential energy retrofitting projects in China are relatively traditional and basic for contractors, convincing them that their professional expertise is enough to cope with the construction work. A high level of perception about these risks makes homeowners more inclined to safeguard their own interests by making more requests for retrofitting. A high level of risk perception can be viewed as a motivator of proactive measures for risk mitigation, but the effectiveness of some proactive measures, especially taken by non-risk-source-related stakeholder groups, cannot be ensured due to the limitation of individuals' knowledge and external environment factors.

Given the importance of the homeowners-related risks and the possible relationships between the occurrence of these risks and homeowners' high levels of perception of other risks, the thesis investigates how to improve homeowners' cooperation in residential energy retrofitting via information provision. Three hypotheses were developed through literature review to show the conceptual relationship between information and homeowners' cooperation, as well as the mediation role of risk perception and the moderation role of information source credibility in this relationship. Questionnaire surveys, structural equation modelling (SEM), and multiple linear regressions were adopted to test hypotheses. The results reveal the varied roles of different kinds of information in homeowners' cooperation and

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support the mediation effects of risk perception and the moderation effects of source credibility. They are retrofitting benefits and positive information about retrofitting services have directly positive influences on homeowners' cooperation. The indirect effect of service information via risk perception is also significant. Meanwhile, the high credibility of information sources is a prerequisite to these significant effects. Furthermore, the effects of building information and retrofitting technology information on homeowners' cooperation are diverse in different cases. There is no significant direct connection between building information and homeowners' cooperation, but increased building information amplifies homeowners' risk perception due to the poor quality of old residential buildings and which further hinders their cooperative behaviours. This significantly indirect effect also requires the high credibility of information sources. Similarly, increased technology information does not contribute significantly to homeowners' cooperation. Still, influenced by the high credibility of social contacts with laypeople, the roles of retrofitting technology information are changed to be 'significant' from 'insignificant', which can be attributed to the difficulties of laypeople in understanding building technology information.

The thesis finally develops broader strategies from the perspective of the government to mitigate the key risks identified based on the assessment of probability and severity and the risks perceived highly by homeowners. Given the important roles of the government in residential energy retrofitting in China, a theoretical framework was established based on TCT to understand the barriers (e.g., asset specificity, uncertainty, and frequency) to government performing risk-related project activities and mitigating risks. Based on questionnaire surveys with the government officials, both exploratory factor analysis (EFA) and artificial neural network (ANN) were adopted to examine the influence of these factors on the government's behavioural intentions towards project activities related to each risk. The results reveal the importance of asset specificity and uncertainty to project running and risk mitigation. Immaturity in the operation of project activities is the most important obstacle to the government running projects. Environmental uncertainty regarding costs and time restrictions and the immature retrofitting market also needs to be better recognized and valued. Retrofitting complexity and quality is a special uncertain factor because it can motivate to a large extent the government to perform the risk-related project activities well. Through survey respondents' views on risk allocation, the results consider the government to be responsible for the mitigation of risks about homeowners' awareness and cooperation, the expertise of technical staff, technical standards, and building quality. Accordingly, this study develops mitigation strategies for these risks in two aspects of immaturity in the operation of project activities and costs and time restrictions. It recommends the government to disseminate information, build energy

service databases, exchange technology experience, enhance building diagnosis, develop financing diversification, and promote project post-evaluation. The results also reveal the role of the government as the supervisor and guide in the mitigation of other important risks regarding on-site construction and post-retrofitting usage. It further provides the corresponding recommendations from the perspective of the maturity of the retrofitting market and suggests the government to encourage certification of both material and personnel standards.

The findings of this thesis are conducive to the understanding and mitigation of risks in the whole process of residential energy retrofitting projects in the HSCW zone of China, providing both scholarly and practical value. Prior studies focus on the investment risks in energy retrofitting in terms of the energy efficiency gap, and few of them explored the risks in the whole process of retrofitting projects from the perspective of project management. Particularly in the Chinese context, risks in energy retrofitting projects have been barely considered. This study fills in the research gap. It identifies systematically important risks existing in the current retrofitting projects and develops a set of strategies to mitigate these risks. This research methodology can be applied to the risk research of residential energy retrofitting in other climatic regions and even the renovation of buildings for other uses. This thesis contributes to the body of knowledge by conducting a systematic exploration of risks in retrofitting projects. In terms of the practical contributions, it does not only enable project managers to recognize the priority of the risks and further prioritize resources to cope with the key issues in future retrofitting projects, but also provides a set of strategies for the government to understand risk causes and guide them to tackle these issues at its source for promotion of residential energy retrofitting. Homeowners can also benefit from these strategies by maximizing homeowners' living quality and housing value in future retrofitting projects.

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Samenvatting

Sinds 1978 heeft de vastgoedsector zich snel ontwikkeld in China. Vooral in de jaren tachtig en negentig werden er grote aantallen woongebouwen gebouwd. De kwaliteit en prestaties van deze gebouwen lieten echter te wensen over vanwege het gebrek aan een adequaat wettelijk kader (inclusief voorschriften en normen). Meer dan 70% van de gebouwen in China heeft een hoog energieverbruik. Dit geldt vooral voor de hete zomer en koude winter (HSCW)-zone, waar meer dan de helft van de woongebouwen werd gebouwd zonder thermische isolatiemaatregelen (Fu, 2002). Er zijn en worden weliswaar energetische renovaties uitgevoerd, deze zijn in vergelijking met de enorme voorraad gebouwen echter lang niet genoeg, vooral in de HSCW-zone (MOHURD, 2017). Om de klimaatdoelstelling te bereiken, is het noodzakelijk om de energetische renovaties in de HSCW-zone van China te versnellen. De huiseigenaren zijn echter over het algemeen niet bereid om grote veranderingen aan te brengen (bijv. de renovatie van de gebouwschil; Baldwin et al., 2018). Ook niet als ze kunnen profiteren de bijkomende voordelen, zoals de verbetering van de bouwkwaliteit en de verhoging van het woongenot en comfort. Deze onwil komt vooral vanwege de risico's die men ziet en de negatieve effecten die dat heeft op de projecten in termen van kwaliteit, tijd, kosten, en dergelijke. De renovatieprojecten blijken inderdaad kwetsbaar te zijn voor problemen als kostenoverschrijdingen, slechte kwaliteit, projectvertragingen, enz. (Hwang et al., 2015; Liu et al., 2020). Het risico is dus een belangrijke factor die het succes van energetische renovatieprojecten in de weg staat (Zou et al., 2007). Het proces wordt gekenmerkt door onzekerheden, die verschillende risico's met zich meebrengen over de houding en het gedrag van huiseigenaren, coördinatie van belanghebbenden, de kwaliteit van ontwerp en constructie, enz.

Dit proefschrift heeft tot doel de rol van risico's in het proces van energetische renovatieproces van woongebouwen in kaart te brengen. De volgende probleemstelling staat daarbij centraal: Welke risico's belemmeren de uitvoering van het energie renovatieproces van woongebouwen in de HSCW-zone van China en welke strategieën kunnen deze risico's beperken? Deze studie gebruikt het risicobeheerproces als een conceptueel kader voor het verkennen van de strategieën voor risicobeperking bij de energetische renovatie van woongebouwen in de HSCW-zone van China. Dit proces omvat risico-identificatie, risicobeoordeling en risicobeperking. Transactiekostentheorie (TCT) is in dit raamwerk opgenomen en draagt bij aan risico-identificatie en -beperking. Projectfasen

en belanghebbenden worden in overweging genomen om de risico's in het hele proces van energierenovatieprojecten systematisch te identificeren. Dit onderzoek beoordeelt het belang van deze geïdentificeerde risico's in zowel objectieve als subjectieve aspecten. De objectieve beoordeling houdt rekening met twee parameters van risicowaarschijnlijkheid en impact, terwijl subjectieve beoordeling de risicoperceptie van verschillende belanghebbenden meet. Mitigatiestrategieën worden onderzocht vanuit het perspectief van het gedrag van belanghebbenden om het optreden van belangrijke risico's te verminderen die zijn geïdentificeerd op basis van zowel objectieve als subjectieve beoordelingen. Gezien het belang van aan huiseigenaren gerelateerde risico's en de sleutelrol van de overheid bij energetische renovatieprojecten, zijn huiseigenaren en de overheid in deze studie de belangrijkste doelgroepen voor het ontwikkelen van mitigatiestrategieën. De provincie Anhui kan worden beschouwd als representatieve provincie voor de energetische renovatie van woongebouwen in de HSCW-zone en is daarom geselecteerd voor het uitvoeren van de casestudies voor gegevensverzameling.

Dit proefschrift onderzoekt eerst de belangrijkste risico's die uitvoering van energetische renovatieprojecten belemmeren vanuit het perspectief van objectieve risicobeoordeling. Een lijst van risico's voor energierenovaties met overwegingen van TC's werd vastgesteld door middel van literatuuronderzoek en semigestructureerde interviews met belangrijke belanghebbenden in de casestudies. De vragenlijstonderzoeken met de belanghebbenden zijn uitgevoerd om de waarschijnlijkheid en ernst van elk geïdentificeerd risico te meten. Alle risico's werden gerangschikt in volgorde van belangrijkheid door twee methoden van risicomatrix en Borda-beoordeling te combineren.

Uit de resultaten blijkt dat de tien belangrijkste risico's meestal worden geassocieerd met huiseigenaren en aannemers en zich voordoen tijdens de bouwfase op de bouwplaats. Drie van de vier grootste risico's die de uitvoering van projecten belemmeren, worden geassocieerd met huiseigenaren: hun lage bewustzijn tijdens het voorbereidingsproces en hun slechte samenwerking en opportunistisch gedrag tijdens de uitvoering. In termen van risico's zijn de aannemers, met uitzondering van de huiseigenaren, de meest kritische belanghebbenden bij de bouw. Hun professionele expertise, constructiemanagement en veiligheidsmanagement zijn de belangrijkste bronnen van projectrisico's. Het belang van het risico dat verband houdt met de competentie van aannemers, komt met name voort uit de ernstige gevolgen ervan in plaats van de waarschijnlijkheid van optreden.

De resultaten laten ook zien dat informatie-, onderhandelings- en monitoringkosten de belangrijkste bronnen zijn van TC's met betrekking tot tien belangrijke risico's.

Informatiekosten komen het meest voor worden vooral gedragen door de overheid en de huiseigenaren. Deze kosten worden gemaakt door de activiteiten van de overheid om energetische renovatieprojecten, technische normen en technisch personeel te selecteren. Echter ook door het gedrag van huiseigenaren om informatie te verzamelen over de energiebesparing van de renovatie, de betrouwbaarheid van het bouwbedrijf en de kwaliteit van het onderhoud.

Onderhandelingskosten houden verband met huiseigenaar gerelateerde risico's en vloeien voort uit het overtuigen van huiseigenaren in een vroeg stadium en het heronderhandelen voor de eisen van huiseigenaren die verder gaan dan het plan tijdens de bouw ter plaatse. Monitoringskosten zijn gerelateerd aan het onderhoudsrisico en worden gemaakt door de monitoring van energiezuinige technieken en onderhoud van gebouwen na renovatie.

Om de risico's meer diepgaand te onderzoeken, analyseert dit proefschrift de risicoperceptie van verschillende belanghebbenden. Op basis van de risicolijst die is samengesteld op basis van de eerder genoemde literatuurstudie en interviews, zijn er vragenlijsten opgesteld om de risicoperceptie van vier groepen belanghebbenden te onderzoeken: overheid, huiseigenaren, ontwerpers en aannemers. Bij elk van deze vier groepen is de risicoperceptie gemeten. Daaruit blijkt dat de risicoperceptie bij verschillende belanghebbenden divers is vanwege hun verschillen in verantwoordelijkheid en belangen. De overheid maakt zich als organisator en beslisser meer zorgen over de risico's die de algehele handhaafbaarheid van energetische renovatieprojecten beïnvloeden. Risicopercepties van ontwerpers en aannemers sluiten ook aan bij hun rol als dienstverlener, gericht op de risico's die de vervulling van hun taken belemmeren, zoals onvoldoende objectieve informatie en niet-coöperatieve partners. Daarentegen besteden huiseigenaren meer aandacht aan de risico's voor hun eigen belangen, zoals de kwaliteit van materialen, de competentie van aannemers, de werkprestaties van aannemers en de veiligheid van de bouwplaats. Met name wat betreft sommige bouw gerelateerde risico's (bijv. de capaciteiten van aannemers, materiaalkwaliteit en de legalisering van de acties van aannemers), hebben huiseigenaren een aanzienlijk hogere risicoperceptie dan andere groepen belanghebbenden.

De overheid selecteert aannemers door middel van aanbestedingen gaat ervan uit dat de aannemers de overheidsinvesteringsprojecten serieus nemen. De huidige energie-efficiënte technologieën die worden toegepast in de meeste energetische renovatieprojecten in China zijn relatief traditioneel en eenvoudig voor aannemers, waardoor zij ervan overtuigd dat hun professionele expertise voldoende is om de bouwwerkzaamheden aan te kunnen. Een hoge mate van perceptie van deze risico's maakt huiseigenaren meer geneigd om hun eigen belangen veilig te stellen door meer verzoeken om aanpassingen te doen. Een hoge mate van risicoperceptie kan worden gezien als een motivator voor proactieve maatregelen voor risicobeperking, maar de effectiviteit van sommige proactieve maatregelen, met name genomen door niet-risicobron gerelateerde groepen belanghebbenden, kan niet worden gegarandeerd vanwege de beperking van de individuele kennis en externe omgevingsfactoren.

Gezien het belang van de aan huiseigenaren-gerelateerde risico's en hun perceptie daarvan onderzoekt dit proefschrift hoe de samenwerking met huiseigenaren door middel van informatievoorziening kan worden verbeterd. Via literatuuronderzoek zijn drie hypothesen ontwikkeld om de relatie tussen informatievoorziening en de medewerking van huiseigenaren aan te tonen. Daarbij is tevens ingegaan op de bemiddelende rol van risicoperceptie en de matigende rol van de geloofwaardigheid van de informatiebronnen. De hypothesen zijn getoetst aan de hand van empirisch onderzoek (via een vragenlijst) en het toepassen van structurele vergelijkingsmodellering (SEM) en lineaire regressies.

De resultaten laten zien dat de rol van verschillende soorten informatie voor huiseigenaren uiteenloopt en ondersteunen de hypothese dat bemiddelingseffecten van risicoperceptie en de matigende effecten van geloofwaardigheid van belang kunnen zijn. Het geven van informatie over de voordelen van energetisch renoveren heeft een direct positieve invloed op de bereidheid van huiseigenaren om in te stemmen met de plannen. Ook het indirecte effect van service-informatie via risicoperceptie is significant. Wel is daarbij de hoge geloofwaardigheid van informatiebronnen een voorwaarde voor deze significante effecten. Bovendien zijn de effecten van bouwinformatie en het aanpassen van technologie-informatie op de instemmingsbereidheid van huiseigenaren in verschillende gevallen divers. Er is geen significant direct verband tussen bouwinformatie en de instemmingsbereidheid van huiseigenaren. Meer bouwinformatie versterkt de risicoperceptie van huiseigenaren vanwege de slechte kwaliteit van oude woongebouwen en wat hun coöperatief gedrag verder belemmert. Dit significant indirecte effect vereist ook een hoge geloofwaardigheid van de informatiebronnen. Evenzo draagt meer technologische informatie niet significant bij aan de medewerking van huiseigenaren. Toch wordt, onder invloed van de hoge geloofwaardigheid van sociale contacten met leken, de rol van het achteraf aanpassen van technologie-informatie veranderd in 'significant' van 'onbeduidend', wat kan worden toegeschreven aan de moeilijkheden van leken om informatie over bouwtechnologie te begrijpen.

Het proefschrift ontwikkelt tot slot bredere strategieën vanuit het overheidsperspectief om de belangrijkste risico's te verminderen op basis van de beoordeling van waarschijnlijkheid en ernst en de risico's die door huiseigenaren als hoog worden ervaren. Gezien de belangrijke rol van de overheid bij de energetische renovatieprojecten in China, is een theoretisch kader opgesteld op basis van TCT om de belemmeringen te begrijpen voor de overheid om risico gerelateerde projectactiviteiten uit te voeren en risico's te verminderen. Op basis van vragenlijstonderzoeken met overheidsfunctionarissen zijn zowel verkennende factoranalyse (EFA) als kunstmatig neuraal netwerk (ANN) uitgevoerd om de invloed van deze factoren op de gedragsintenties van de overheid te onderzoeken. Onvolwassenheid in de uitvoering van projectactiviteiten is het belangrijkste obstakel bij het uitvoeren van projecten door de overheid. Milieuonzekerheid met betrekking tot kosten en tijdsbeperkingen en de onvolwassen markt voor energetisch renoveren moet ook beter worden erkend en gewaardeerd. Het achteraf inpassen van complexiteit en kwaliteit is een bijzondere onzekere factor omdat het de overheid in hoge mate kan motiveren om de risico gerelateerde projectactiviteiten goed uit te voeren. De respondenten beschouwen de overheid verantwoordelijk voor het beperken van risico's met betrekking tot het bewustzijn en de instemminsbereidheid van huiseigenaren, de expertise van technisch personeel, technische normen en de kwaliteit van gebouwen. Op basis daarvan zijn er strategieën ontwikkeld om deze risico's te beperken op het gebied van de onvolwassenheid in de uitvoering van projectactiviteiten en kosten- en tijdbeperkingen. De overheid zou de informatie beter moeten te verspreiden, databases voor energiediensten opbouwen, technologische ervaring uitwisselen, de diagnose van gebouwen verbeteren, financieringsdiversificatie te ontwikkelen en de evaluatie van projecten achteraf te bevorderen. Het proefschrift gaat ook in op de rol van de overheid als toezichthouder en gids bij het verminderen van andere belangrijke risico's met betrekking tot bouwuitvoering en gebruik achteraf. Het geeft verder de bijbehorende aanbevelingen vanuit het perspectief van de professionaliteit van de energetische renovatiemarkt en beveelt de overheid aan om certificering van zowel materiaal- als personeelsnormen aan te moedigen.

De bevindingen van dit proefschrift verhogen het begrip in en de beperking van risico's in het energetisch renovatieproces van woongebouwen in de HSCW-zone van China en bieden zowel wetenschappelijke als praktische waarde. Eerdere studies richtten zich op de investeringsrisico's bij energetische renovatieprojecten in termen van de energie-efficiëntiekloof. Slechts weinigen gingen in op de risico's in het volledige energetisch renovatieproces vanuit het perspectief van projectmanagement. Met name in de Chinese context is er nauwelijks rekening gehouden met risico's bij energetische renovatieprojecten. Dit onderzoek vult deze onderzoek lacune op. Het identificeert systematisch belangrijke risico's die bestaan in de huidige energetische renovatieprojecten en ontwikkelt een reeks strategieën om deze risico's te beperken. Deze onderzoeksmethodologie kan worden toegepast op het risico-onderzoek van de energetische renovatie van woongebouwen in andere klimaatregio's van China en zelfs op de renovatie van gebouwen voor ander gebruik.

Dit proefschrift draagt bij aan de wetenschap door een systematische verkenning van risico's bij energetische renovatieprojecten van woongebouwen in China. Wat de praktische bijdragen betreft, stelt het projectmanagers in staat de prioriteit van de risico's te herkennen en middelen verder te prioriteren om de belangrijkste problemen in toekomstige renovatieprojecten het hoofd te bieden. Daarnaast biedt het proefschrift een reeks handvatten voor de overheid om risico-oorzaken te begrijpen en strategieën om deze problemen bij de bron aan te pakken voor de bevordering van energetisch renovatieprojecten voor woongebouwen. Ook huiseigenaren kunnen profiteren van deze strategieën door het maximaliseren van de woonkwaliteit en woningwaarde in toekomstige energetische renovatieprojecten.

1 Introduction

1.1 Introduction

1.1.1 Building energy efficiency in the international context

Global warming is destroying the ecological environment and has posed a serious threat to the survival of human and animals. Compared with pre-industrial levels, global average annual surface temperatures have risen by 1°C, of which over 0.3°C results from CO_2 emissions from coal (IEA, 2019a). Coal-fired electricity generation was the greatest contributor to the increase in CO_2 emissions in 2018, accounting for 30% of global emissions (IEA, 2019a). There is a unidirectional causality between fossil energy consumption and climate change. Yet, effective strategies for energy consumption may mitigate global warming (Akhmat et al., 2014). Renewable energy is an effective substitute for fossil fuels in terms of emission savings, but its use cannot keep up with massively increasing electricity demand (IEA, 2021). Energy use needs to be more efficient to reduce the overall energy demand.

To combat climate change, more attention has been paid to building energy efficiency around the world. Worldwide, 28% of CO_2 emissions and 30% of final energy consumption are attributed to the building sector in 2018 (IEA, 2019b). Many countries, such as the EU countries and the US, have regarded the building sector as the key to reduce national energy consumption and achieve low-carbon emissions. In particular, existing buildings have a great potential for improving energy efficiency. , Public policies in many countries increasingly address energy efficiency in these buildings (Levine et al., 2007). The GlobalABC Global Roadmap has viewed building retrofitting as one of the key priorities for reducing the burden of energy use (UNEP, 2016). In fact, 70% of energy consumption and 60% of carbon emissions in the building sector are from residential buildings (IEA, 2019c). Existing residential buildings have thus become important targets for energy conservation and emission reduction globally.

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1.1.2 The status quo of residential energy retrofitting in China

To respond to this global trend, in the 1990s, the Chinese central government started to develop the political targets of building energy efficiency. Energy demand and emissions of urban residential buildings account for 38% and 42%, respectively, of the national building totals (CABEE, 2020). Accordingly, since 2006, energy retrofitting of residential buildings has been the focus of building energy efficiency. In the latest national plan issued in 2021, the building sector is still the focus of reducing carbon emissions. It is necessary to deepen building energy efficiency, contributing to peaking carbon dioxide emissions before 2030 and achieving carbon neutrality before 2060.

There are five main building climatic regions in China, including the severe cold zone, the cold zone, the hot summer and cold winter (HSCW) zone, the warm zone, and the hot summer and warm winter zone. The northern heating region (including the severe cold and cold regions) and the HSCW zone are the key zones for residential energy retrofitting. The main target of residential energy retrofitting in China is the old urban residential quarters, especially those built before 2000. These quarters are usually composed of apartment buildings of multi-ownership, which are also the most common form of urban residential buildings in China. In general, the homeowners own their apartments and can lawfully possess, utilize, profit from, and sell them. All homeowners share ownership of the common parts of a building, but the state owns the land. Homeowners have the right to manage the property themselves or entrust others to manage it. When introducing standardized property management, homeowners are obligated to pay property service fees, including those days used for the maintenance and repair of the property. Homeowners also need to pay special maintenance funds for the maintenance, renewal, and renovation of the shared parts of buildings and shared facilities and equipment. The central government issued the relevant policy in 2015 to encourage the use of such funds in residential energy retrofitting. However, the laws and regulations related to property management and special maintenance funds have only been issued in the last two decades. In this case, most of the old residential quarters depend on the co-owners' self-management, and there are no available public funds to invest in the renovation.

Currently, energy retrofitting of residential buildings is mainly led by the local government, and relies heavily on government funding. The guidelines for residential energy retrofitting issued in 2012 state that homeowners should bear a certain amount of retrofitting expenses, but there is no stipulation on the specific share. Given the difficulty of raising funds from homeowners and the willingness of provincial governments to respond to national policies on building energy efficiency quickly, government funding is still the most important source of funds for energy retrofitting in practice, especially in the HSCW zone. Under the local government-led model, the retrofitting funds mainly come from the provincial and municipal governments, especially the latter. For this reason, the local government, as the subsidizer, has more decision-making power than homeowners in residential energy retrofitting projects. In general, the central government directly assigns the retrofit tasks to the construction department of the local government. The local construction department is involved in the whole process of retrofitting projects. It is responsible for project planning and selection, the selection of the design and construction companies, and assistance with project inspection and acceptance, etc. However, such heavy dependence on government funding is also an important barrier to the promotion of residential energy retrofitting due to the limitation of the government budget. Moreover, homeowners are the beneficiaries but are rarely involved in decision-making. This leads to some conflicts with the local government or other stakeholders during the project implementation, due to disagreements or differences of interest.

The energy retrofitting of existing residential buildings in China targets the building envelopes. The *Technical Specification for the Retrofitting of Residential Buildings on Energy Efficiency* issued in 2012 is the only evaluation-based policy targeting existing residential buildings. This specification applies to energy retrofitting projects in various climatic zones. Still, the detailed retrofitting measures are 'tailored' to meet the requirements of the energy-saving design standards for new residential buildings in different climate zones. Following this technical specification, the main retrofitting items include the building envelope (namely, roof insulation, external wall insulation, and replacement of exterior windows). The renovation of the district heating system is also involved in some projects in severe cold and cold zones.

1.1.3 The importance of residential energy retrofitting in the HSCW zone

China has made significant achievements in energy retrofitting residential buildings, but retrofitting development is imbalanced between different regions. In the 11^{th} five-year period (2006-2010), residential energy retrofitting was first implemented in the northern heating region of China. The HSCW zone was highlighted as another key region of residential energy retrofitting during the 12^{th} five-year period (2011-2015). More than one billion m^2 of retrofitting projects have been completed in the last decade or so, in which the northern heating region has much more contributions than other climatic regions. At present, the northern heating region has formed a large-scale energy efficiency retrofit, while retrofitting in the HSCW zone is still in its infancy. Such imbalance seems to be because of the extreme climate in winter in the northern region and the earlier issuance of national policies on building energy efficiency for this region.

The HSCW zone is experiencing a considerable increase in household energy consumption due to its uncomfortable climate and increased demand for living comfort. The temperatures in summer and winter in this region are much more extreme than those in other locations at the same latitude throughout the world (Wang et al., 2009). The number of air-conditioners per household in the HSCW zone is the largest in China, and the length of time of using air-conditioners for cooling is also much more than that in most of the other regions (IEA, 2019d). In recent years, air-conditioning power consumption in this region has started to rise rapidly in summer. There is a significant shortage of power every summer in some provinces. In addition, in the winters in the same HSCW zone, the heavy use of heating facilities led to a great increase (about 575%) in heating energy consumption of residential buildings (Lin et al., 2016). Thus, promoting residential energy retrofitting in the HSCW zone is one of the main tasks in the national plan for the energy efficiency of buildings in China. The central government views it as an effective means to promote energy conservation and emission reduction, and tackle climate change to achieve carbon neutrality before 2060.

In addition to energy issues, the poor quality of the existing building stock negatively affects the quality of life for homeowners and even results in some safety issues. The urban building stock in the HSCW zone amounted to about 9 billion m^2, of which residential buildings accounted for 66% in 2012 (Liu et al., 2017). About 54% of these buildings were built without any thermal insulation measures (Fu, 2002). In China, it was not until the late 1990s that laws and regulations on housing construction quality were generally officially issued and implemented. The poor quality of the building stock arises from both poor design and poor construction, and is a common problem throughout China (Baldwin et al., 2018). Moreover, the maintenance of old residential quarters rarely used property management companies, so this depended heavily on the self-management by the co-owners. The lack of proper maintenance would lead to the quick deterioration of buildings (Schmidt et al.). As shown in Figure 1.1, these problems led to the poor performance of the building envelope, and are harmful to the living comfort and safety of buildings.

FIG. 1.1 Aging residential buildings

Energy retrofitting contributes to the improvement of building quality and residents' living quality. Some energy-efficient technologies used for building envelopes improve thermal comfort and reduce the level of outdoor noise infiltration and increase the value of buildings (Jakob, 2006). Some moisture problems can also be eliminated by improving the building insulation to further reduce residents' health risks (Levine et al., 2007). Moreover, structural strengthening has been required to be integrated into energy retrofitting in some projects in China, which is conducive to the enhancement of building safety. However, there is no evidence that the general public has a strong appetite for energy retrofitting in China (Baldwin et al., 2018). For example, whilst homeowners might be willing to approve some simple renovations (e.g., the replacement of lighting), there is also reluctance to renovate the building envelope (Baldwin et al., 2018).

1.1.4 Risks hindering the implementation of energy retrofitting

Homeowners' resistance to energy retrofitting can be attributed to their concerns about poor project performance that mainly results from project risks. Low post-retrofit performance is one of the main problems of building energy retrofitting in China (Liu et al., 2020), hindering the achievement of the quality objective. Green retrofitting of buildings is vulnerable to the problem of project delay (Hwang et al., 2015). Delays further lead to an increase in project costs (e.g., the overhead costs and labour costs) (Hwang et al., 2015). The poor building quality, mentioned above also increases the probabilities of cost overruns (Wilkinson et al., 2009). Although homeowners generally do not have to bear the costs of energy retrofitting, projects' quality and schedule issues would damage their interests.

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The risks, namely, future and uncertain factors/events that negatively influence project performances (e.g., costs, quality, and time), can be viewed as a major cause of these deviations from project objectives. Risks need to be addressed to ensure project success and the achievement of project objectives (Zou et al., 2007). The reduction in building retrofit risks contributes to enhancing stakeholders' willingness to adopt green retrofitting technologies (Brown et al., 2014).

Energy retrofitting residential buildings in China is characterized by uncertainty regarding the organization, coordination, finance, technology, etc. For example: (a) energy retrofit is more costly compared with energy conservation in new-build buildings (Li and Colombier, 2009), but depends on central and local government incentive funds due to the lack of the multi-channel financing mechanism (Bao et al., 2012; Lu et al., 2014); (b) the dispersing of the ownership of a building leads to a strong possibility of disagreement on energy retrofitting (Lv and Wu, 2009) . Similarly, diverse personal circumstances in terms of education levels, lifestyles, income levels, and occupations, may result in homeowners' poor satisfaction and acceptance in retrofitting technologies among tens or even hundreds of homeowners (Liu et al., 2015); (c) more stakeholders are involved in energy retrofitting projects, and the interactions among various stakeholders lead to a more complicated project process than in conventional projects (Klotz and Horman, 2009; Liang et al., 2015; Liang et al., 2017). In particular, retrofitting projects in China involve various government departments at various levels, but the lack of a joint system for government departments at the high levels in China is likely to lead to poor coordination (Lv and Wu, 2009); (d) retrofit technologies in China remain in a relatively backward state so that complex technologies cannot be supported (Lv and Wu, 2009). Meanwhile, there is a shortage of related professionals due to the lack of professional education and training on building energy retrofit (de Feijter et al., 2019).

Influenced by these uncertainties, residential energy retrofitting projects in China are exposed to various risks, which hinder the implementation of retrofitting projects and the achievement of project objectives. This thesis aims to deepen the understanding of the risks in the whole process of residential energy retrofitting. Then, it proposes risk mitigation strategies to smoothen the implementation of retrofitting projects in the HSCW zone of China. The remaining sections of this chapter are organized as follows. Section 1.2 introduces the risk management process into the framework of exploring risk mitigation strategies, including risk identification, assessment, and mitigation involving different project stages and stakeholders. Section 1.3 adopts transaction costs theory to help identify and mitigate risks. Section 1.4 presents the research approach, including problem statement, research questions, research scope, data collection, and data analysis methods. Finally, section 1.5 introduces the structure of this thesis and the main content of each chapter.

1.2 Retrofitting process and stakeholders in the Chinese context

1.2.1 Process of residential energy retrofitting

According to *Technical Guidelines for Energy Efficiency Retrofitting of Existing Residential Buildings in the HSCW zone* issued in 2012, the main retrofitting items in this area are roof insulation, external wall insulation, replacement of external windows, and sun-shading measures. Some other technologies, including replacing the lighting in common areas with LED energy-saving lamps, replacing energy-saving air-conditioning systems, and applying renewable energy in the hot water supply system, are also mentioned, but the latter two measures are very rare in practice.

In terms of the universal retrofitting process, Ma et al. (2012) conducted a review study on existing building retrofits and divided the overall operation of a building retrofit into five major phases: (a) project setup and pre-retrofit survey; (b) energy audit and performance assessment; (c) identification of retrofit options; (d) on-site construction and commissioning; and (e) validation and verification of energy savings.

In China, there is no fixed and uniform process for residential energy retrofitting projects. Retrofitting measures and processes are diverse in different provinces. The central government only provides some general guidance for provincial governments by developing national documents.

According to the *Guide for Energy Saving Retrofit of Existing Residential Buildings*, the overall process of residential energy retrofitting also mainly includes five steps: (a) Conduct the investigation on the basic situations of residential buildings, and compile and submit the plans of energy retrofitting for approval; (b) Determine the retrofitting projects and raise funds; (c) Conduct the survey on building information and residents' attitudes, make retrofitting schemes, work out construction drawings and project budgets, and sign the agreement with households; (d) Implement the retrofits; and (e) Inspect and accept the projects, and guide occupants for use and maintenance (MOHURD, 2012a).

Technical Guidelines for Energy Efficiency Retrofitting of Existing Residential Buildings in the HSCW Zone provides more details for building evaluation (MOHURD, 2012b). It requires on-site investigation and evaluation of the safety and quality of buildings before the implementation of energy efficiency retrofitting. If the safety performances of the main load-bearing structures of buildings fail to comply with applicable standards, structure strengthening and energy efficiency retrofitting should be carried out simultaneously. Testing and evaluation on the thermal performance of building envelope and energy efficiency of energy-use equipment before and after retrofitting are also stressed. The retrofitting schemes should be determined based on the pre-evaluation results. The post-evaluation is made based on the simulation method to calculate the retrofitting effects. Such evaluation applies the actual energy-use pattern to assess energy-efficiency effects, comfort improvement, and economic benefits.

According to Ma et al. (2012), *Guide for Energy Saving Retrofit of Existing Residential Building* (MOHURD, 2012a) and *Technical Guidelines for Energy Efficiency Retrofitting of Existing Residential Building in the HSCW Zone* (MOHURD, 2012b), this study classifies the whole process of energy retrofit projects in the HSCW zone in China into five stages (see Table 1.1).

TABLE 1.1 Theoretical phases and tasks in residential energy retrofitting projects in the HSCW zone of China

Project stages	Tasks at each stage
Regional survey and project setup	1 General investigation on existing residential buildings and database establishment
	2 Key-point investigation on typical buildings
	3 Analyse data and determine retrofitting projects
Work out bespoke plans on project design and raise funding	1 Detailed investigations on indoor and outdoor conditions and environment of the investigated buildings
	2 Conduct a resident information investigation and advocate for energy efficiency retrofit
	3 Work out designs and project budgets (Design company, government and households)
	4 Sign a retrofit agreement with each household
Construction bidding and construction preparation	1 Carry out construction bidding
	2 Make construction organization design and special construction plan
	3 Clean the spot before the site construction
Site implementation	1 Training for construction
	2 Site implementation
Inspection, acceptation, and use	1 Inspect and accept the retrofitting projects
	2 Evaluation on retrofit results
	3 Guide households for use and maintenance

1.2.2 Key stakeholders involved in the retrofitting process

Various stakeholders are involved in the process of residential energy retrofitting. Menassa (2011) defined stakeholders in sustainable retrofitting projects as people who can benefit directly or indirectly from retrofitting projects. They classified the main stakeholders into five groups, namely: owners, tenants, investors, operators, and designers. Bao et al. (2012) and Lu et al. (2014) identified the stakeholders in the northern region of China, including central and local government, property rights units, residents, energy-saving service firms, heating enterprises, design units, property management units, material suppliers, construction units, etc.

By comparison, stakeholders in the HSCW zone in practice differ from the above stakeholders. At present, only the northern areas in China have achieved the central heating for urban residential buildings, while most residential buildings in the HSCW zone were constructed without heating systems. In this case, heating enterprises are not seen as stakeholders. This study focuses on urban residential buildings with individual ownerships, as mentioned before. Moreover, the Chinese government has developed a monetary and market-oriented housing system since 1998. Under such circumstances, old residential buildings are almost privatized. Property rights units can thus be excluded. In terms of property management units, old residential quarters are heavily dependent on self-management by the co-owners. In China, laws, regulations, and industry standards related to property management were gradually issued after 2003, and most of the old residential quarters built before 2003 rarely introduced professional property managers to maintain the buildings before retrofitting, which means that property management units do not need to be considered. Besides, energy-saving service companies are mainly involved in the retrofitting mode of EPC (Energy Performance Contracting) that has not been applied to the residential building sector. Hence, they are not also engaged in retrofit projects in practice. Therefore, in this study, the main stakeholders in retrofit projects can be divided into four groups, namely: occupants, government, designers, and contractors.

1.3 Risk management with transaction costs considerations

Risk management is necessary for smoothening the implementation process of residential energy retrofitting. Effective risk management is important to the success of a project by improving project management performance (Flanagan and Norman, 1993). The decrease in occurrence probability and mitigation of risk impacts are the key to risk management (Xia et al., 2017). The risk management process generally consists of risk identification, risk assessment, and risk mitigation (PMI, 2013). Transaction Costs Theory (TCT) can be a theoretical basis to identify and mitigate risks in residential energy retrofitting projects. Transaction costs (TCs) can be goods and services, travel costs, labour, and time spent in a transaction (Coggan et al., 2010). The TCs of retrofitting projects mainly include costs of due diligence, negotiation costs, and monitoring costs, and are incurred by project activities, such as seeking partners and retrofitting solutions, making a contract, and monitoring contractual agreements, technology installation, and performance of technology use (Kiss, 2016). High TCs are an important barrier to implementing energy-efficient technologies in the building sector (Lee and Yik, 2002). Transaction Costs Theory (TCT) has been adopted to risk research in other fields. Bahli and Rivard (2005) identified the risk factors of information technology outsourcing based on TCT. Jin (2010) used TCT to allocate risks between the public and private partners in order to achieve effective risk management in privately financed public infrastructure projects. Similarly, TCT contributes to risk identification and mitigation in energy retrofitting of residential buildings.

1.3.1 Risk identification

Stakeholders and project stages need to be considered in risk identification, which is crucial to effective risk management. There are two attributes of risks: nature and source, and the source refer to the party that causes and creates the risks (Perrenoud et al., 2015). In building projects, the risk source may generally be the main stakeholder groups of projects, including architects, contractors, suppliers, government, and clients (Perry and Hayes, 1985; Zou et al., 2007). A stakeholder-risk analysis is helpful to the development of a comprehensive risk list, a better understanding of risk causes, and the formulation of effective project management strategies (Yang and Zou, 2014; Yang et al., 2016). In general, risks spread through the whole process of building projects, from the planning stage to the completion and usage stage (Perrenoud et al., 2015; Zou et al., 2007). Different risks occur at diverse stages, and information regarding when certain risks emerge is beneficial to risk identification and can provide a systematic method for risk management (Perrenoud et al., 2015). Therefore, this study links risk identification to different project stages and stakeholders to have a comprehensive understanding of various risks.

1.3.1.1 A generic perspective

Previous studies have explored the risks in energy retrofitting residential buildings, and these provide a general picture of projects risks in the international context. As shown in Table 1.2, these generic risks involve various aspects of retrofitting projects, such as organization, technology, context, finance, management, and post-retrofitting operation. The existing studies also consider these risks to be associated with different stakeholders. Organizational risks are mostly related to goals, plans, and support policies developed by the government. Technical and management risks are primarily concerned with industry stakeholders, especially contractors. Contextual and operational risks are mainly associated with occupants, resulting from their negative attitudes and post-retrofitting behaviours. Financial risks are primarily relevant to occupants, government, and designers.

TABLE 1.2 A list of risks in energy retrofitting of residential buildings from previous studies internationally

Type	Potential risks	Reference	Stakeholders associated with risks			
			O	G	D	C
Policy and organization	Inappropriate energy efficiency goals and plans	(Bao et al., 2012; Caputo and Pasetti, 2015; Hoppe, 2012)		√		
	Frequent change in support schemes	(Biekša et al., 2011)		√		
	Lack of local government's coordination and support	(Bao et al., 2012)		√		
Technology	Inaccurate energy audit	(Biekša et al., 2011)			√	
	Lack of technical staff with specific expertise	(Boutaud et al., 2011; Ferreira and Almeida, 2015; Mills et al., 2006; Olgyay and Seruto, 2010; Tuominen et al., 2012)			√	
	Lack of knowledge on installation of energy-efficient equipment	(Boutaud et al., 2011; Ferreira and Almeida, 2015; Fylan et al., 2016; Goldman, 1985; Olgyay and Seruto, 2010; Sunikka-Blank and Galvin, 2012; Tuominen et al., 2012)				√
Context	Lack of awareness of the need for energy -efficiency retrofitting	(Caputo and Pasetti, 2015) (Biekša et al., 2011)	√			
	Negative public attitude towards retrofitting	(Biekša et al., 2011; Pettifor et al., 2015)	√			
	Insufficient information regarding the buildings	(Mitropoulos and Howell, 2002)			√	
Finance	Inability to raise internal funds	(Biekša et al., 2011; Li, 2009; Lo, 2015)	√	√		
	Lack of access to external capital	(Bao et al., 2012; Caputo and Pasetti, 2015; Dahlhausen et al., 2015; Li, 2009)		√		
	Artificial exaggeration of retrofitting costs	(Biekša et al., 2011)			√	
On-site implementation and management	Poor performance in coordination and cooperation	(Rovers, 2014)	√			√
	Poor quality control	(Fylan et al., 2016; Goldman, 1985)				√
Operation	Changes in occupants' behaviours	(Booth and Choudhary, 2013; Rosenow and Galvin, 2013; Terés-Zubiaga et al., 2015)	√			
	Occupants' inappropriate usage mode	(Boutaud et al., 2011; Mills et al., 2006; Olgyay and Seruto, 2010; Walker et al., 2014)	√			
	Inadequate maintenance	(Mills, 2003)	√			

Note: G = Government, H = Homeowners, C = Contractors, D = Designers.

1.3.1.2 A transaction costs perception

Uncertainty is a core assumption in TCT. TCs are generally influenced by three dimensions of transactions (asset specificity, uncertainty surrounding transactions, and transaction frequency) and two behavioural assumptions (bounded rationality and opportunism) (Williamson, 1985; Williamson, 1975). The impacts of these factors on TCs are largely due to imperfect information, and uncertainty is an important cause of imperfect information. In fact, many transaction problems are concerned with information asymmetry (Clemons and Hitt, 2004). All the transactions are conducted in an uncertain situation, and people need to make more effort to collect information (Aubert et al., 2004). High TCs restrict actors' information collection activities so that they have to act in an uncertain state (McCann, 2013). The existence of uncertainty prevents actors from imagining all possible contingencies so that contracts cannot be written completely (Williamson, 2002). Ex-post TCs would be raised, such as maladaptation costs and the costs of dispute settling (Williamson, 1985). Meanwhile, uncertainty also makes it hard for contracting parties to assess others' contributions, increasing the possibility of opportunism from specific assets (Shrader, 2001; Sutcliffe and Zaheer, 1998).

TCs can be a lens to identify more risks in the energy retrofitting of residential buildings in China. Project stages can be viewed as transactions involving various tasks and stakeholders. TCs are incurred by project activities among the stakeholders at different project stages when stakeholders depend on each other to deliver service and exchange information. High TCs are more likely to be incurred in the small size of projects (Painuly et al., 2003). The scale of residential energy retrofitting is limited in the HSCW zone of China due to the slow progress, further causing more TCs. Risks in this study are closely related to the existence of uncertainty. High TCs would impede exchange, production, and even economic growth (North, 1986). Similarly, the transactions of retrofitting would be hindered when more TCs are caused by uncertain factors regarded as risks. It is necessary to manage risks throughout the whole project process (Raj and Wadsamudrakar, 2018). Stakeholders should also be considered in risk analysis and mitigation due to their roles as risk sources (Prum and Del Percio, 2009). TCs related to project stages and stakeholders, provide a lens for identifying the risks impeding the implementation of residential energy retrofitting, and also contribute to a better understanding of risks.

1.3.2 Risk assessment

Risk can be assessed from different perspectives. Objective and subjective factors are closely related to risk assessment and risk mitigation. The objective view tends to characterize risk in terms of certain types of objective facts, namely facts about the probabilities and their outcomes (Hansson, 2010). Risk probability and severity of its impacts are the most common parameters to assess risks (Lyons and Skitmore, 2004; Taroun, 2014). Accurate estimates on the probability of risk occurrence and the severity can reflect the accurate risk profile (Tavanti and Wood, 2017). Subjective risks are used interchangeably with perceived risks (Hansson, 2010). Risk perception can be viewed as a subjective evaluation of risks by stakeholders and is based on risk categories, personal experience, culture, etc. (Pidgeon, 1998; Rohrmann, 2008). Stakeholders tend to apply a simplified decision-making process instead of the actual situation to perceived risks. There is diverse subjective rationality and risk perception due to the difference in stakeholders' culture (de Camprieu et al., 2007). Sjöberg (1999) pointed out that it is different for experts and the public to reach an agreement upon risk perception, and thought that experts' risk perception may be more realistic and is a kind of factual judgment. However, everyone, even including experts, can be biased when judging risks (Pidgeon, 1998). The public also has something valuable to contribute, and their insights should be respected (Slovic, 1987). Incorporating and considering a wider range of knowledge, both experts and the public, into risk assessment helps avoid misjudgments resulting from narrow and inadequate knowledge (Bickerstaff, 2004). To summarise, this study considers both expert assessment and public perception as the basis of risk mitigation.

1.3.3 Risk mitigation

Risk mitigation is made based on risk identification and risk assessment in order to address potential risks that are given priorities. Risk mitigation strategies usually include reactive strategies implemented as contingency plans after risks occur; and proactive strategies implemented to mitigate risks before they occur (Kern et al., 2012). Compared to the reactive approach that plans nothing about reducing risk probability, proactive mitigation strategies can be either the decrease in risk probability or the reduction in risk impacts in advance of risk occurrence (Kırılmaz and Erol, 2017). Prevention is better than a cure and required risk managers to take urgent risks quickly (Kleindorfer and Saad, 2005). Thompson and Perry (1992) highlighted the importance of risk avoidance and concluded that the most valuable risk management should be implemented at an early stage in a project to avoid risks in the subsequent project work. Such risk management is also recognized and considered by Kartam and Kartam (2001) to be achieved by reducing the probabilities of risk occurrence. The decrease of risk occurrence is thus the focus of developing risk mitigation strategies in this study to perform effective risk management.

Stakeholder participation is critical to risk mitigation in energy retrofitting projects. Stakeholders are the main risk sources in projects (Skelton and Thamhain, 2006; Ward and Chapman, 2008). Risks occur in stakeholders' work in projects and are posed by their behaviours, but these stakeholders are also the most primary resources for risk mitigation (Skelton and Thamhain, 2006). The probability of risk occurrence can thus be reduced through the improvement of stakeholder behaviours in retrofitting projects. TCs are important factors affecting stakeholders' performance in projects. As the purpose of risk management, the achievement of project goals and objectives is based on the completion of the specific tasks and activities in each stage (Munns and Bjeirmi, 1996). Various TCs are incurred by the project activities related to risks, such as costs of searching for project parties and retrofitting solutions, costs of negotiating with other project parties, and costs of monitoring technology installation and use. One of the main reasons it is difficult to measure TCs is that most of the transactions would not occur when TCs are high (Benham and Benham, 2000). High TCs can be the barriers to the execution of these risk-related project activities, which does not only impede project running but can also be the cause of risk occurrence. Therefore, TCs can be a lens to explore the approach to risk mitigation.

1.4 Research approach

1.4.1 Problem statement

To speed up residential energy retrofitting in the HSCW zone, the barriers to retrofitting projects need elimination. Energy retrofitting contributes to improving building quality and living comfort, but has not been accepted by the public (Baldwin et al., 2018). Usually, homeowners are reluctant to make major changes to their homes (e.g. the renovation of the building envelope) (Baldwin et al., 2018), which stem from the negative impacts of risks on project performance in quality, time, costs, etc. Indeed, the retrofitting projects are vulnerable to the problems of cost overruns, poor quality, project delay, etc. (Hwang et al., 2015; Liu et al., 2020), which would damage homeowners' interests. Energy retrofitting of residential buildings in China is exposed to various risks due to uncertainties regarding finance, organization, coordination, technology, etc. Thus, the risk is an essential factor hindering these project objectives and project success (Zou et al., 2007).

An exploration of risks is required from the perspective of project management in order to promote the smooth implementation of retrofitting projects. However, the prior studies mainly focus on the investment risks of retrofitting projects from an investor's viewpoint. The identified risks are mainly related to cost increases and the decrease in energy-saving in performance. These studies view risk as to the basis for retrofitting projects' investment decision-making and the selection of retrofitting technology. Correspondingly, risk mitigation strategies proposed by these studies aim to protect investors' interests rather than improve the smoothness of project implementation. Besides, the government-led model leads to the uniqueness of residential energy retrofitting projects in China. Its implementation process and the participants are different from those in the international context. Still, few research studies on the risks of energy-saving retrofit project specific to the Chinese context.

Given the limitations in previous studies, it is necessary to investigate the risks in residential energy retrofitting projects and develop effective risk mitigation strategies to promote the smooth implementation of retrofitting projects in the HSCW zone of China. This research is conducted following the risk management process, involving risk identification, risk assessment, and risk mitigation. Transaction costs theory is applied to risk identification and risk mitigation. Risk assessment considers the judgment of different groups (including professional practitioners and the public) on the importance of various risks. Meanwhile, considering the important role of the government in residential energy retrofitting in China, this study put forward some policy recommendations for mitigating project risks.

1.4.2 Research aim and questions

Based on the problem statement, this thesis aims to deepen the understanding of risks in the whole process of residential energy retrofitting and develop risk mitigation strategies to smoothen the implementation of retrofitting projects in the HSCW zone of China. It answers the following main research question:

What are the risks hindering the implementation of residential energy retrofitting projects in the HSCW zone of China, and what strategies can mitigate these risks?

To answer the research question mentioned above, it requires the systematic identification and assessment of risks existing in residential energy retrofitting and the exploration of mitigation strategies targeted for mitigating different risks, which are highlighted in the above sections. Risks are identified systematically from two perspectives of project stages and stakeholders. This study assesses the importance of these risks in both objective and subjective aspects. The objective assessment considers risk probability and impact parameters, while subjective assessment is viewed as risk perception. Mitigation strategies are explored to reduce the occurrence of key risks identified from both objective and subjective assessments.

The main research question is broken down into four key questions. These questions are addressed in Chapters 2, 3, 4, and 5, respectively.

Chapter 2 answers the key question:

1 **What are the key risks hindering the implementation of residential energy retrofitting projects in the HSCW zone of China from the perspective of objective risk assessment?**

TOC

This key question can be separated into the following sub-questions:

- a What are the major tasks and stakeholders involved in the whole process of retrofitting projects in practice?
- b What are the risks that should be given a higher priority based on risk probability and impact?
- c What are the focuses of mitigating key risks from the perspectives of projects stages and stakeholders?
- d What are the TCs associated with key risks?

Based on the theoretical risks listed in Chapter 2, Chapter 3 answers the key question:

2 **What are the important risks perceived subjectively by different stakeholders in residential energy retrofitting projects in the HSCW zone of China?**

This key question can be separated into the following sub-questions:

- a What are the differences in risk perception among key stakeholders?
- b What are the reasons causing diverse perceptions of different risks?
- c What are the influences of different levels of risk perception on stakeholder's behaviours?

Chapter 2 highlights the importance of the risks related to homeowners' participation and cooperation, and Chapter 3 points out the possible links between these risks and homeowners' high levels of perception of other risks. On this basis, Chapter 4 answers the key question:

3 **What retrofitting information contributes to the improvement of homeowners' cooperation in residential building energy retrofits in the HSCW zone of China?**

This key question can be separated into the following sub-questions:

- a What is information having a significant influence on the level of homeowners' cooperation?
- b What is the role of risk perception in the relationships between information and homeowners' cooperation?
- c What role does the source of information play?

Aiming at both the key risks identified in Chapter 2 and the risks highly perceived by homeowners in Chapter 3, Chapter 5 answers the key question:

4 **What are the strategies for mitigating risks of the government-led energy retrofitting projects in the HSCW zone of China?**

This key question can be separated into the following sub-questions:

a What are the factors causing the increase in the TCs incurred by risk-related project activities?
b What are the TCs-related factors affecting the government's performance in various risk-related project activities?
c What role does the government play in the mitigation of different risks?
d What are policy recommendations to mitigate risks?

1.4.3 Research scope

This thesis focuses on the residential buildings owned by private individuals in the HSCW zone of China. As mentioned earlier, such residential buildings are generally composed of multi-apartments, and private individuals own their own apartments but share the ownership of the common areas of buildings. Currently, energy retrofitting residential buildings in China is mainly implemented in three climate regions: the severely cold zone, the cold zone, and the HSCW zone. Compared with the first two regions, residential buildings especially old buildings in the HSCW zone are commonly built without installing the heating system. This thesis focuses on retrofitting projects involving the thermal insulation of building envelopes, which is the most common retrofitting item, including windows, doors, roofs, and external walls. Besides, sunshades and LED energy-saving lamps are also installed in some projects.

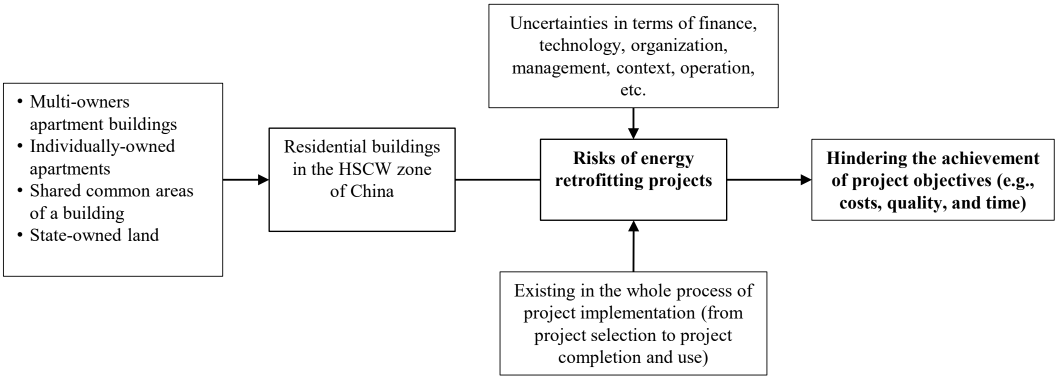

FIG. 1.2 Research scope

Figure 1.2 presents a detailed definition of risks in the energy retrofitting of residential buildings. First, risks are considered from the perspective of the whole process of project implementation. This process involves a series of tasks and activities from project selection to project completion and use. Second, risks are various uncertain factors on finance, technology, organization, management, operation, context, etc. Third, risks have negative impacts on project performance in costs, time, quality, etc.

1.4.4 Research approach: data and methods

This thesis uses mixed research methods to collect qualitative and quantitative data to achieve research objectives. As a representative province of residential energy retrofitting in the HSCW zone, Anhui province was selected as the case area for data collection in the thesis (Figure 1.3). Anhui province is located on the boundary between the northern and southern climatic regions in China, and has a typical climate with cold winter and hot summer. Winter and summer are the two seasons with the longest duration, each as long as four months. In recent years, the average temperature in July and August has been above 29 °C, and the highest temperature in some cities can reach nearly 40 °C. The average temperature in January is as low as about 1 °C, and the lowest temperature in some cities is below -10 °C.

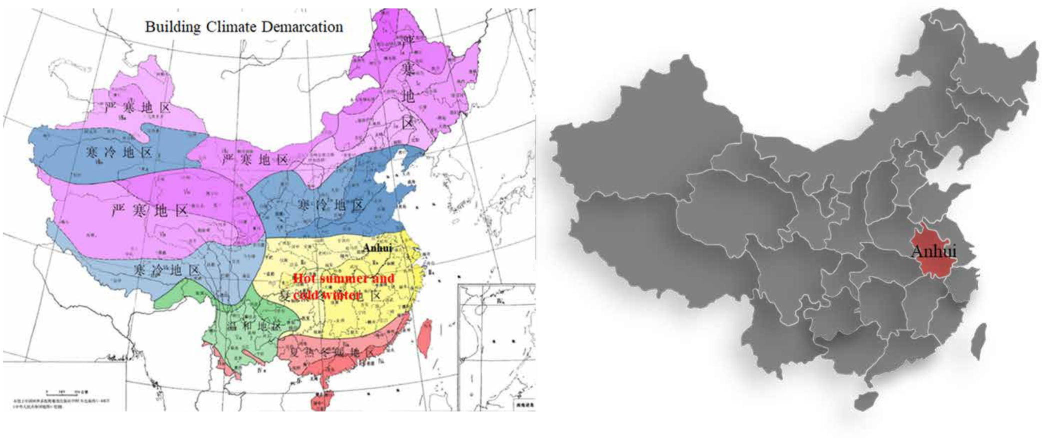

FIG. 1.3 Location of Anhui

Anhui province has started the promotion and implementation of residential energy retrofitting since 2013. The central government also listed its provincial capital city as a pilot base for energy retrofitting of residential buildings in the HSCW zone in 2012. Since 2016, the provincial government has encouraged applying energy-efficiency measures to the province-wide existing residential buildings. The renovation of residential buildings in Anhui mostly is mainly for residential quarters built before 2000. Thermal insulation of the building envelope is the main energy retrofitting item among the completed projects. The routine operation of retrofitting is to replace windows and doors with those with higher insulation levels and to use new thermal insulation materials to improve the insulation effectiveness of walls and roofs.

This thesis collected data from different cities in Anhui province for empirical analysis, since retrofitting projects in Anhui province are implemented under the same industry standards and policy environment. The thesis selected three energy retrofitting cases from three cities. The interview data comes from the participants of the three cases, the municipal government of the provincial capital city, and the provincial government. On this basis, Chapter 2 collected the risk assessment data from professional practitioners in three case cities and the provincial capital city. Similarly, Chapter 3 discusses the risk perception of different stakeholders in five cities based on the interview data, including three case cities. With the expansion of the retrofitting scale, Chapter 4 and Chapter 5 carried out questionnaire surveys in more cities. The data on the influence of information on homeowners' cooperation in Chapter 4 was collected from six cities. Chapter 5 collected data from the municipal government departments in nine cities to explore risk mitigation strategies.

The overview of the research method is shown in Figure 1.4.

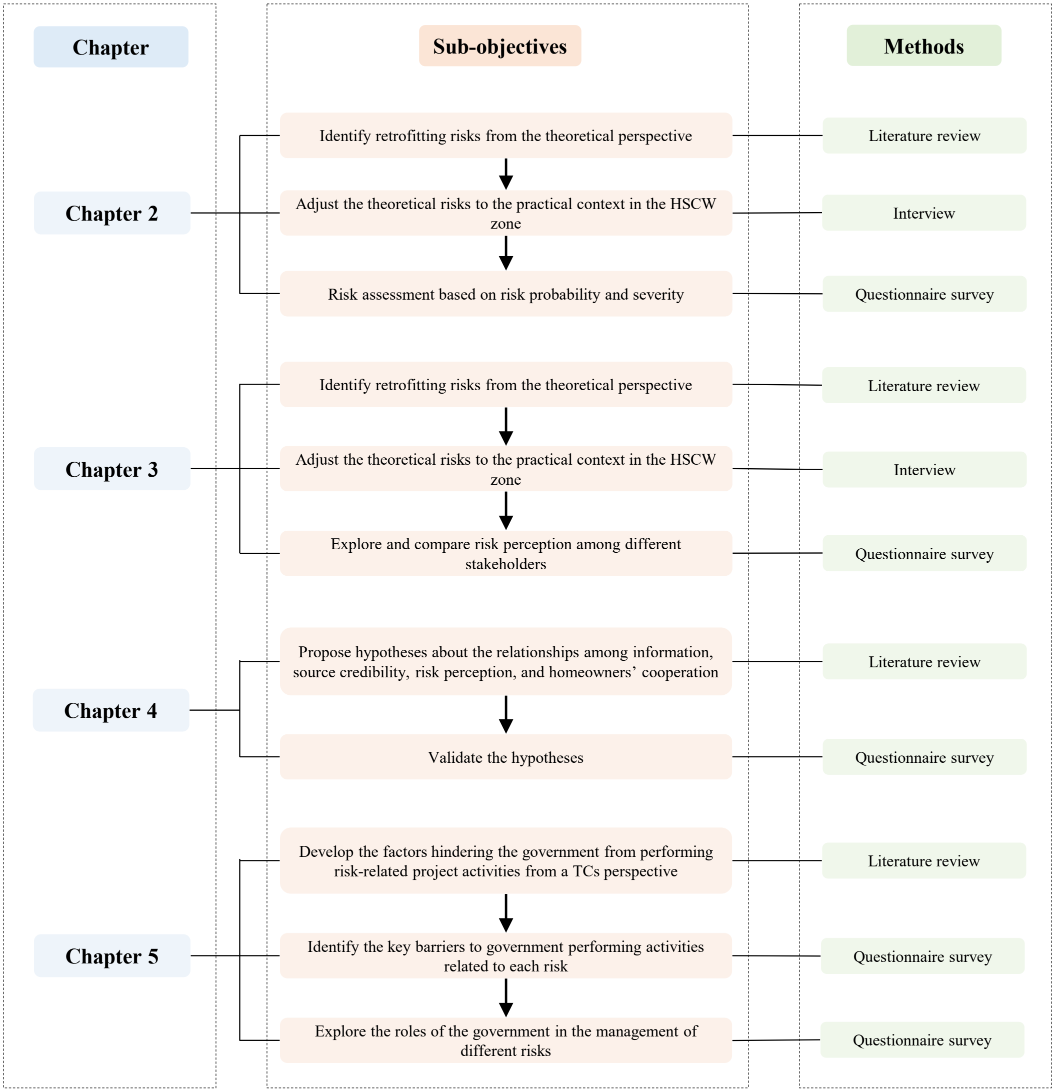

FIG. 1.4 Overview of research methods

Chapter 2 collected data through literature review, interview, and questionnaire survey to explore the key risks hindering the implementation of residential energy retrofitting projects in the HSCW zone of China. A theoretical list of energy retrofitting risks with TCs considerations was identified through literature review. Then, semi-structured interviews were conducted with 22 interviewees. Most interviewees are the participants of three selected case projects, representing four stakeholder groups of the government, homeowners, contractors, and designers, respectively. The interviews helped to test the existence of the theoretical risks, and adjust the theoretical retrofitting process to the practice. A questionnaire survey was conducted based on the risk list adjusted by interviewees. The respondents are professional practitioners having experience in retrofitting projects. They were asked to measure the probability and severity of each risk. The questionnaires were delivered to these participants via personal delivery or e-mails. Finally, 67 valid questionnaires were collected and used for data analysis. This chapter ranks all risks in order of significance by combing two methods of risk matrix and Borda voting. The chapter considers ten top risks as key risks and analyses project stages, stakeholders, and TCs relevant to these key risks.

Following the literature review and interview applied in Chapter 2, another questionnaire survey was conducted based on the risk list to explore risk perception of different stakeholders, as reported in Chapter 3. Potential respondents are from four stakeholder groups, namely the government, homeowners, contractors, and designers. Homeowners are from three case projects, and the other three stakeholder groups are the participants of completed retrofitting projects in five cities. Respondents were asked to measure the level of their concern about each risk from their subjective point of view. The questionnaires were distributed via personal delivery, and a total of 172 valid questionnaires were collected. Parametric tests were adopted to make the comparison of risk concerns within each stakeholder group, among all stakeholder groups, and within different pairs of groups. In addition, based on the interview data, this chapter discusses the influence of risk perception on stakeholders' proactive actions for risk mitigation and analyses the key stakeholders of effective risk mitigation.

In Chapter 4, a theoretical framework involving retrofitting information, risk perception, information source credibility, and homeowners' cooperation was established to explore how to improve homeowners' cooperation through information provision. Three hypotheses were first developed through literature review to show the conceptual relationship between information and homeowners' cooperation, as well as the mediation role of risk perception and the moderation role of information source credibility in this relationship. A questionnaire survey was conducted to examine these hypotheses. Questionnaires were sent out via a mobile social application to homeowners from twelve residential quarters in six cities. The target residential quarters were built in the years 1980-2005 and have not been renovated. Each variable, namely information, information source credibility, risk perception, and homeowners' cooperation, is composed of several sub-factors. This questionnaire survey asked homeowners to measure all sub-factors constituting the four kinds of variables. Finally, 413 valid questionnaires were used for data analysis. Both structural equation modelling (SEM) and multiple linear regressions were adopted to test hypotheses.

In Chapter 5, an analysis framework was established based on TCT to explore the risk-related barriers to government-run retrofitting projects. This thesis first develops a series of factors in three aspects of asset specificity, uncertainty, and frequency through literature review. These factors prevent the government from performing risk-related project activities and further increase the probability of risk occurrence. An online questionnaire survey was conducted. The potential respondents are working in the local Housing and Urban-rural Development department and are involved in local residential energy-retrofitting projects as government representatives. They were asked to measure three kinds of variables (including the government's behavioural intentions towards the risk-related project activities, asset specificity, and environmental uncertainty). The variable of frequency was measured based on the objective data. Meanwhile, respondents were asked their opinions on the management responsibility for each risk. The respondents were asked which risks the government assumes the primary responsibilities of management for, which risks can be allocated to other stakeholders (as the principal managers), and what roles the government plays in managing these risks. A total of 88 valid questionnaires were used for data analysis. Both exploratory factor analysis (EFA) and artificial neural network (ANN) were adopted to examine the roles of TC-related factors in government performing project activities related to each risk. Based on the varied roles of the government in the management of different risks, the chapter provides policy recommendations for the mitigation of each risk from different perspectives of the above TC-related factors.

1.5 Outline of the thesis

As shown in Figure 1.4, this thesis incorporates a collection of academic papers (Chapter 2 to 5). These papers are authored by the writer of this thesis and have been published in or submitted to international, peer-reviewed scientific journals. Chapter 2 explores the key risks hindering the implementation of residential energy retrofitting projects in the HSCW zone of China. Chapter 3 probes stakeholders' risk perception in residential energy retrofitting projects in the HSCW zone of China. Chapter 4 is designed based on the results of both Chapter 2 and Chapter 3, aiming to investigate how to improve homeowners' cooperation in residential energy retrofitting via information provision. Chapter 5 aims to develop the strategies for mitigating the key risks identified in Chapter 2 and the risks perceived highly by homeowners in Chapter 3. Finally, Chapter 6 summarizes the previous chapters, answers all research questions, and provides the broader implications and theoretical and practical contributions.

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2 Exploring Key Risks of Energy Retrofit of Residential Buildings in China

with Transaction Cost Considerations

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ABSTRACT Energy retrofit of residential buildings is an approach to reduce worldwide energy consumption. Residential energy retrofitting in China mostly focuses on multi-owner residential buildings with composite ownership that dozens of private homeowners own their apartment and jointly own the common parts of a building. The implementation of residential energy retrofit faces many risks, causing the slow retrofit process in the hot summer and cold winter (HSCW) zone of China. Transaction cost theory (TCT) is conducive to enrich an in-depth understanding of risk inventories in the energy retrofitting context. This study aims to explore the key risks in retrofit projects of residential buildings in the HSCW zone with transaction costs (TCs) considerations, in order to provide the direction for effective risk management. First, based on the theoretical risks with TCs considerations, interviews were conducted to adjust the risk list and to connect these risks with stakeholders and stages. Second, a questionnaire survey was made based on two parameters of risk probability and severity, and then ten top risks were chosen as key risks through both a risk matrix and Borda count. The results show that most of the key risks are associated with homeowners and contractors, involving retrofit awareness, cooperation performance, opportunism, professional expertise, construction management, safety management, and maintenance, of which most occur at the stage of on-site construction. Information cost is the largest source of TCs relevant to these key risks and is mainly borne by the government and homeowners. TCs can also provide a lens for the retrofitting in other countries to understand risks, and the decrease in information costs contributes to effective risk management both in China and in the international context.

KEYWORDS Energy retrofit; Risk management; Transaction costs; Stakeholders

2.1 Introduction

Building energy use has become the main driver for the growing worldwide energy consumption and CO_2 emissions. The final energy use in buildings grew from 118 EJ in 2010 to about 128 EJ in 2019, and CO_2 emissions from buildings peaked over 10 $GtCO_2$ in 2019, occupying 30% and 28% of the global total respectively (IEA, 2020). China had faster growth in CO_2 emissions related to buildings than many other countries between 2000 and 2017 (see Figure 2.1). Worldwide, 70% of building energy demand and 60% of emissions are attributed to residential buildings (IEA, 2019a). Urban residential buildings also play a dominant role in building energy consumption and carbon emissions in China, sharing 38% and 41% of the national total respectively (CABEE, 2018). The total area of urban residential buildings was 24.8 billion m^2 by 2015 in China, and energy-efficient dwellings only account for about 40% (CABEE, 2017; MOHURD, 2017). Existing buildings, especially old residential buildings, have the enormous potential of energy saving in China (Ouyang et al., 2011).

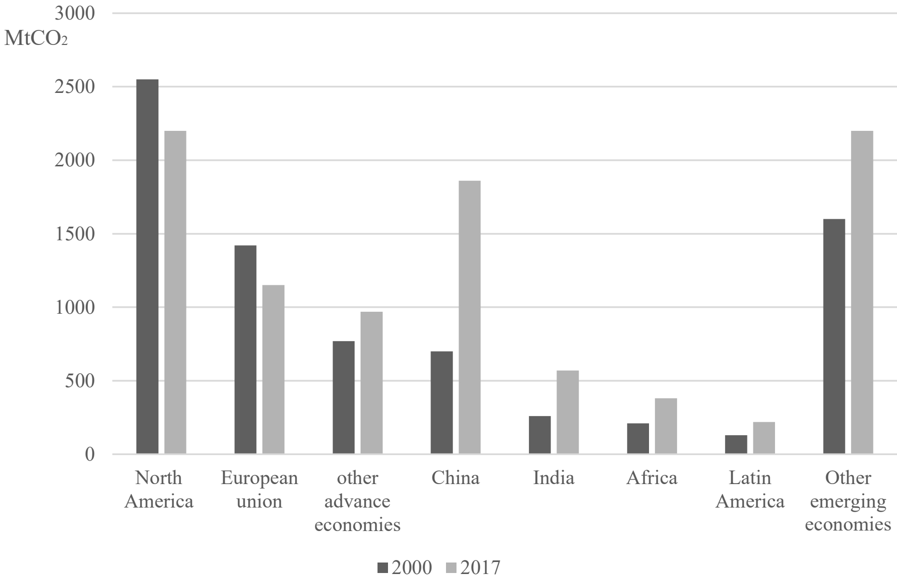

FIG. 2.1 Building-related CO_2 emissions by region, 2000-2017 (IEA, 2019a)

The large differences in climate conditions among different regions in China result in different regional characteristics of building energy consumption. The hot summer and cold winter (HSCW) zone (0–10 °C in the coldest month and 25–30 °C in the hottest month) is of particular significance in building energy efficiency of China (Xu et al., 2013). The number of air conditioners per household in this zone is the largest in China, and the households tend to use air conditioners for longer cooling hours than most of the other regions (IEA, 2019b). Heavy use of heating facilities resulted in a considerable increase (circa 575%) in the residential heating energy consumption in the HSCW zone in the past several years (Lin et al., 2016). Existing building stock in urban locations within the HSCW region covered an area of about 9 billion m^2, of which residential buildings comprised 66% in 2012 (Liu et al., 2017). 54% of existing urban dwellings in this region were constructed without any thermal insulation measures (Fu, 2002). Only 70.9 million m^2 of retrofit projects were completed in the HSCW zone during the 12^{th} Five-Year Plan period (2011–2015), a much slower rate than the northern region with 990 million m^2 (MOHURD, 2017). Therefore, it is necessary to accelerate the implementation of residential energy retrofitting in China's HSCW zone.

Energy retrofits for residential buildings in China are faced with many risks in the implementation process. Risks are characterised by uncertainty and negative impacts on project objectives (Chia, 2006). Risks in this study are concerned with uncertain events and exert a negative influence on performances of energy retrofitting projects (e.g. costs, quality, organization, and management). The multi-owner apartment building is the main form of urban residential buildings in China and is also the main object of energy retrofitting. Private homeowners own their apartment and all homeowners share ownership of the common parts of a building, but the land is owned by the state. Uncertainty lies in these retrofitting projects in terms of adequacy of investors (Bao et al., 2012; Lu et al., 2014), consistency in homeowners' opinions on retrofitting (Lv and Wu, 2009), homeowners' satisfaction and accuracy of using installed technology (Liu et al., 2015), performance in cooperation among various government departments (Lv and Wu, 2009), the perfection of technology (Lv and Wu, 2009), etc. These uncertainties pose a series of risks about the economy, homeowner attitudes and behaviours, stakeholder coordination, and technology to residential energy retrofitting in China. Such risks are also the main barriers to energy retrofitting in China, and impede the progress and the achievement of project objectives.

Risk identification is the premise of risk management, and the lens of transaction costs (TCs) can be considered to identify these risks. TCs are different from production costs and are the economic equivalent of friction in physical systems (Williamson, 1985). The residential energy retrofitting process can be divided into stages involving various stakeholders. TCs occur in terms of tasks or concerns amongst the stakeholders at different stages (transactions) when stakeholders rely on each other to deliver service and exchange information. Energy retrofitting of residential buildings is in its infancy in the HSCW zone of China, so that the scale of retrofitting is limited. A smaller size of projects is more likely to cause high TCs (Painuly et al., 2003). Uncertainty is a core assumption in transaction cost theory (TCT). All the transactions are conducted in an uncertain situation with imperfect information so that more effort needs to be made to collect sufficient information (Aubert et al., 2004). Uncertainty is considered to increase the probability of opportunism from specific assets, resulting in an increase in TCs of exchange (Sutcliffe and Zaheer, 1998). TCs can be searching costs for the right partners and technical information, learning costs to understand the incentives and how to apply, negotiation costs to handle conflicts and disagreements, etc. For example, uncertainty about qualified technical providers incurs TCs to search for skilled staff and employ external experts (Matschoss et al., 2013). From the new institutional economics perspective, when TCs are too large, the exchange, production, and economic growth would be inhibited (North, 1986). Those uncertain factors viewed as risks in energy retrofit projects give rise to the increase in TCs and thus hinder the retrofitting transactions. Risks need to be managed in the whole process of projects (Raj and Wadsamudrakar, 2018), and stakeholders as risk sources should also be analysed to mitigate the risk impacts (Prum and Del Percio, 2009). TCT can not only provide a more targeted identification of risks hindering the implementation of the energy retrofit, but also help have a better understanding of risks, by taking both the project stages and stakeholders into consideration.

This study aims to identify the critical risks hindering the implementation of residential energy retrofitting projects in the HSCW zone of China, from different stages and stakeholders with TCs considerations. TCT can enrich an in-depth understanding of risk inventories in the energy retrofitting context. Two hypotheses are proposed as follows: (1) different phases of the renovation process induce various TCs, and different stakeholders also associate with TCs differently; (2) different stages and stakeholders have varying levels of importance due to the differences in the priority of their relevant risks. This study provides a holistic understanding of the significant risks in the whole process of energy retrofit projects and, thus, contributes to developing effective measures of risk management in China. The findings also provide the local government with policy directions towards facilitating residential energy retrofitting in China. The TCT-based method can help recognize the risks in energy retrofitting projects in other countries.

The rest of the study is organized as follows. Section 2.2 presents the generic risks from the previous studies and TCT-based risks. Section 2.3 provides the methodology used in this study. Section 2.4 shows the results, including a risk list adjusted by Chinese practitioners and risk ranking according to the risk matrix and Borda count. Section 2.5 presents the discussion on the key risks. Section 2.6 draws the conclusions.

2.2 Literature review

2.2.1 Retrofit process and stakeholders in the Chinese context

In the Chinese context, there is no fixed and uniform process for energy retrofit projects. Each provincial government has its own retrofitting measures and procedures, and the documents developed by the central government can only offer limited guidance. *Guide for Energy Saving Retrofit of Existing Residential Buildings* (MOHURD, 2012a) and *Technical Guidelines for Energy Efficiency Retrofitting of Existing Residential Building in the Hot Summer and Cold Winter Zone* (MOHURD, 2012b), published by the central government, provide some reference to advise on the retrofitting process. By summarizing these official technical guidelines, this study classifies the overall process of energy retrofit projects in the HSCW zone in China into five stages: regional survey and project setup, project design and fundraising, construction bidding and construction preparation, on-site construction, and inspection, acceptance, and use.

Menassa (2011) defined stakeholders in sustainable retrofitting projects as people who can benefit directly or indirectly from retrofitting projects. The stakeholders of retrofit projects in the northern region for the residential buildings in China, are considered to be central and local government, heating enterprises, property rights units, residents, energy saving service firms, planning and design units, property management units, material and equipment suppliers, and construction and supervision units (Bao et al., 2012; Lu et al., 2014). Given the characteristics of energy retrofit in the HSCW zone (e.g. few heating systems and few property management units in old residential quarters), this study categorizes four main stakeholders in retrofit projects, namely occupants, government, designers, and contractors.

2.2.2 Risk identification from a generic perspective

Existing research on risks on energy-efficiency investments explores the potential risks leading to lower energy-saving benefits than expected, including cost increase and the decrease in energy-saving performance. Mills et al. (2006) identified several risks concerning energy-cost volatility, completeness of information on facility and environment, equipment performance, maintenance performance, and measurement accuracy. Booth and Choudhary (2013) also mentioned the inaccurate estimation of energy consumption before and after retrofitting, which was considered as the leading cause of the efficiency gap. Similarly, end-users' operation and usage mode after retrofitting was mentioned by Boutaud et al. (2011) and Olgyay and Seruto (2010). Furthermore, the incompetence of technical staff in terms of design and installation was emphasized, involving insufficient design details, lacking installation knowledge, and poor on-site quality control (Boutaud et al., 2011; Fylan et al., 2016; Mitropoulos and Howell, 2002; Olgyay and Seruto, 2010).

A few studies on the promotion of energy retrofit proposed some risks to explain the implementation difficulties in homeowner participation, fundraising, and government support. From the government's viewpoint, public awareness, feasibility of goals and plans, technical knowledge, coordination with citizens, and availability of funds, all bring obstacles to the implementation of energy retrofit projects (Caputo and Pasetti, 2015). For homeowners, low public confidence, lack of consistent and long-term policies, inability to evaluate the retrofit costs, and shortage of information on variations in future heat prices also stop them from retrofitting their homes (Biekša et al., 2011). Besides, poor coordination among different government departments was also highlighted by Bao et al. (2012) in the Chinese context. However, these studies identified risks of energy retrofit projects mainly from a single stakeholder group (e.g. investors, government, and homeowners) rather than from the overall perspective of project implementation. Most of the risks identified in previous studies are viewed as the factors influencing the selection of retrofitting solutions. Those investment risks related to the efficiency gap also only hinder the investment in retrofit, which rarely needs to be considered in the Chinese context due to the role of the local government as the investor. It is necessary to identify the risks in residential energy retrofitting projects in China from the project management perspective on promoting retrofitting processes. TCT can be applied to explore the barriers of transaction activities based on inter-organizational relationships in the transaction process, and thus can provide a reference point for risk identification to enrich the risk list.

2.2.3 Risk identification from a TCs perspective

TCT was introduced by Coase (1937) and developed by Williamson (1975) based on two assumptions of human behaviours (bounded rationality and opportunism) and three transaction characteristics (asset specificity, uncertainty, and frequency). Bounded rationality arises from the human mind's cognitive limitations and imperfect information (Selten, 1998; Simon, 1957). Opportunism refers to the claim that humans act out of self-interest and with guile (Williamson, 1993). In some cases, uncertain factors make it difficult for parties in a transaction to make a perfect contract, taking all circumstances into consideration, which also provides the incentive for opportunistic behaviours (Pilling et al., 1994; Walker and Weber, 1984). To be specific, influenced by uncertainty and high costs of comprehensive forecasts, bounded rational organizations and individuals have a limited capacity to find, process, and understand information. Uncertainty can generally result in risks of financial losses on the premise of asset specificity (Dorward, 2001). The characteristic of asset specificity leads to a greater probability of opportunistic expropriation due to changed bargaining power and the threat of transaction termination (Klein et al., 1978).

Uncertainty and asset specificity also result in the risk that one party in a transaction will exploit their own information advantages for misconduct (Parker and Hartley, 2003). According to transaction costs economics, many transaction problems have something to do with information asymmetry (Clemons and Hitt, 2004). With the existence of uncertainties, it is hard for contracting parties to evaluate others' contributions, leading to an increase in the potential for opportunism (Shrader, 2001). Such opportunism is in the form of selective disclosure or distortion of the data, rendering other parties unable to gain access to the actual data (Williamson, 1975). The party undertaking specific investments is more likely to be vulnerable to opportunistic expropriation, such as lower quality of the product/service and price/cost losses, due to their locked-in situation (Klein et al., 1978).

The various sources of TCs can be the basis for risk identification in the whole process of energy retrofit projects. Kiss (2016) summarized the main activities incurring TCs related to implementing energy efficiency projects, including information search and assessment, project preparation, seeking partners, persuading, negotiation, making a contract, implementation, coordination, monitoring, and maintenance. Some of these TCs are related to risks in energy retrofit and arise from (1) a lack of energy efficiency knowledge and project information, (2) uncertainty about reliable partners and willingness of homeowners, (3) uncertainty about partners' compliance with specified terms, (4) uncertainty on possible changes in energy savings, and (5) uncertainty on users' behaviours and maintenance. In fact, these risks are almost consistent with the above generic risks mentioned in previous studies but can be understood from a TCs perspective. These risks also exist in the Chinese context. Energy retrofit is a new concept for residential buildings in the HSCW zone of China. The government and industry stakeholders lack experience in management, coordination, and technical support, which means that they have to bear the corresponding TCs to develop appropriate policies, optimize technical standards, enrich technical knowledge, and improve coordination abilities.

Likewise, homeowners need to search for information to advance their understanding of retrofit. Searching costs are also involved in the design stage to ensure the integrity of information relevant to old residential buildings (e.g. as-built data and the surrounding environment). In addition, the existence of opportunism (e.g. adverse selection in the phase of construction bidding as well as moral hazard and opportunistic negotiation during the on-site construction) would incur more searching costs, bargaining costs, and monitoring costs.

2.3 Research methodology

2.3.1 Three case studies

This study views Anhui province in the HSCW zone of China as the object of empirical analysis. Since 2016, the provincial government has encouraged applying energy efficiency measures to the province-wide existing residential buildings. Anhui province operated more than 300 energy retrofitting projects by 2019. Three energy retrofit projects are chosen from three cities in Anhui province as cases. These three projects were funded jointly by the provincial, municipal and district governments. Government is the only investor in most residential retrofitting projects in China. The basic information on these cases is shown in Table 2.1.

TABLE 2.1 Case information

Case No.		1	2	3
Year of completion		1987	1990s	1998
Year of retrofit		2017	2017	2017
Number of residential buildings		Three five-story buildings	Four five-story buildings, one four-story building, and six two-story buildings	Six six-story buildings
Gross floor area/m2		4,160	25,000	23,600
Number of households		180	247	185
Bid price/CNY		1,284,371	3,700,000	6,310,000
Energy retrofit contents	Windows	√	√	√
	Doors	√		
	External walls	√	√	√
	Roof	√	√	√

These three cases adopted the most common retrofitting measures in the HSCW zone of China, and can reflect the daily practices in this region. The main retrofitting items involved in these projects include exterior windows, roofs, and exterior walls. In these projects, doors and windows were replaced by those with higher levels of insulation, and new thermal insulation materials were also used to improve the insulation effectiveness of walls and roofs. There are differences in building materials (e.g. windows and thermal insulation plates) used among these cases, but these projects were implemented based on the same design standard for energy efficiency of residential buildings issued by Anhui provincial government. This standard was also developed based on the standard for the HSCW zone established by the Chinese central government.

It is shown, based on the case study data, that the majority of apartments in these buildings are owner-occupied. Moreover, only homeowners have the right to determine whether these residential buildings can be renovated and how to renovate them. As a result, homeowners replace occupants as one of the four main stakeholder groups in this study.

2.3.2 Interviews with key stakeholders in cases

Interviews are necessary to adjust the theoretical risks to the Chinese context. Semi-structured interviews were conducted with 22 interviewees from the provincial government, the municipal and district governments in the provincial capital city, and the above three cases, including 10 government officials, 4 designers, 4 on-site construction managers, and 4 homeowners. Table APP.A.1 in Appendix to Chapter 2 presents the profiles of all interviewees.

The government representatives were selected from four levels of government departments of housing and construction, including the provincial government, the municipal government, the district government, and the sub-district administrative office. Given the differences in the departments in charge of residential energy retrofitting between different cities, the government interviewees for different cases were selected from various government levels and departments. The first three officials, from the provincial government and the government of provincial capital, were first interviewed to discuss the general situations of energy retrofit and the common risks affecting the implementation. All the rest were directly involved in three cases and were almost involved in all stages of the energy retrofitting projects. Compared to other stakeholder groups, government interviewees are more familiar with all processes in retrofitting projects, and more qualified to identify risks existing in each stage.

The industry stakeholder representatives from design and construction companies were the primary designers and construction managers in the above cases. In particular, three construction representatives were the chief managers in charge of on-site construction for three projects. These interviewees have a comprehensive view of the risks occurring at the stages of design and on-site construction and can provide more detailed information about these risks.

The homeowner representatives were from three cases. Two of them are the members of homeowners' committees that act on behalf of all the homeowners in a residential quarter. The other two are both homeowners and neighbourhood committee staff. There are no homeowners' committees in some renovated residential quarters, and members of neighbourhood committees are therefore responsible for information transmission in practice. As members of homeowners committees and neighbourhood committees, these interviewees have a better understanding of the potential project risks than ordinary homeowners.

The interview questions mainly focus on three aspects: the work and tasks in the entire renovation process, responsibilities and roles of the stakeholders, and verification of the theoretical risks. Based on interviews, this study can empirically test the existence of the theoretical risks identified from the literature review and TCT, and adjust the theoretical retrofitting process to the practice. Interviews also provide information about the distribution of risks in different project stages and the stakeholders associated with each risk.

2.3.3 Questionnaire survey of professional practitioners

A questionnaire survey was conducted to help collect experts' views to explore the significance of different risks. The questionnaire was designed based on the risk list adjusted by interviewees. The final risk list is presented in Table 2.2, and detailed descriptions for each risk are shown in Table APP.A.2 in Appendix to Chapter 2. These risks are composed of three origins, including reviewing previous studies on retrofit risks, identifying risks in the retrofit context of China based on TCT as a supplement to the above risks collected from the literature review, and adding risks depending on interviewees' feedbacks. This questionnaire comprises two sections: (1) information about the respondents' profile; (2) respondents' evaluation on risk ranking. Risk probability and risk severity are the most common parameters for assessing risks (Lyons and Skitmore, 2004; Taroun, 2014). These two parameters should be considered to assess risks in a project (El-Sayegh, 2008). In the second part of this questionnaire, a Likert scale of 1–5 is used to evaluate the likelihood of risk occurrence (1 = very unlikely, and, 2 = unlikely, 3 = possible, 4 = likely, 5 = very likely) and severity of risk impacts (1 = negligible, 2 = minor, 3 = moderate, 4 = serious, 5 = critical) (El-Sayegh, 2008).

TABLE 2.2 Risks in residential energy retrofitting projects in China

No.	Risks	Sources
R1	Frequent change in demolition policies	Interview
R2	Uncertainty on property right and occupancy	TCT
R3	Lack of awareness of energy efficiency retrofitting	(Biekša et al., 2011; Caputo and Pasetti, 2015)
R4	Lack of government departments' coordination and support	(Bao et al., 2012)
R5	Insufficient funds available	(Bao et al., 2012; Biekša et al., 2011; Caputo and Pasetti, 2015; Dahlhausen et al., 2015; Li, 2009; Lo, 2015)
R6	Insufficient information regarding the buildings	(Mitropoulos and Howell, 2002)
R7	Uncertainty on the on-site conditions	TCT
R8	Lack of technical staff with specific expertise	(Boutaud et al., 2011; Ferreira and Almeida, 2015; Hallikas et al., 2004; Mills et al., 2006; Olgyay and Seruto, 2010)
R9	Lack of appropriate technical standards	TCT
R10	Unqualified building materials	Interview
R11	Adverse selection	TCT
R12	Lack of construction skills	(Boutaud et al., 2011; Ferreira and Almeida, 2015; Fylan et al., 2016; Goldman, 1985; Hallikas et al., 2004; Olgyay and Seruto, 2010; Sunikka-Blank and Galvin, 2012)
R13	Moral hazard	TCT
R14	Poor quality of old residential buildings themselves	Interview
R15	Poor construction management	(Fylan et al., 2016; Goldman, 1985)
R16	Poor safety management	Interview
R17	Poor performance in cooperation	(Rovers, 2014)
R18	Opportunistic renegotiation	TCT
R19	Measurement problems	TCT
R20	Inadequate maintenance	(Boutaud et al., 2011; Mills, 2003; Mills et al., 2006; Olgyay and Seruto, 2010; Walker et al., 2014)
R21	Difficulties in post-retrofit repair	Interview

The questionnaires were delivered to the professionals who have been involved in the local retrofitting projects. The respondents are mostly from the three cities where three cases are selected; the rest are from the government departments in the provincial capital city. The participants have experience in three case projects, if not in other retrofitting projects. The respondents from the municipal governments and the design companies were involved in almost all the retrofitting projects in the city where they are located with good knowledge and experience. Despite some differences between different projects, a broader range of survey data can validate the universality of risks identified from interviews and cases and also reduce the potential prejudices from the minority. This questionnaire survey was used to quantify the significance of these risks, and interviewers' opinions can help understand the results or rankings of quantification.

These responses were collected via personal delivery or e-mails. The response rates of face-to-face questionnaires were higher than those via e-mails, which is possibly due to closer social relations with face-to-face respondents. A total of 150 questionnaires were delivered, and 67 were completed and used in this study. The respondents' profiles are summarized in Table 2.3.

TABLE 2.3 Respondents' profile

	Category	Number
Role	Government Official	18
	Contractor	25
	Designer	24
Years of working experience	< 5 years	10
	5-10 years	23
	10-15 years	18
	>15 years	16

2.3.4 Data analysis method

Tests for normality of data of each variable of each risk were first made by SPSS. Q-Q plot and values for skewness and kurtosis were used for checking normality. Q-Q plot is a visual inspection of the distribution. The normal Q-Q plot of each variable presents an approximately straight diagonal line, meaning normally distributed data. Skewness and kurtosis were also measured to judge whether data distributions of this study deviate from normal. A z-score was obtained by dividing the values of skewness or kurtosis by their standard errors. In small samples ($20 < n < 80$), the critical value of z-score for the normal distribution is ± 1.96 (Wright and Herrington, 2011). All the z-scores in this study are within this range, and more results are shown in Table APP.A.3 in Appendix to Chapter 2. Based on the test results, data of each risk variable are considered to be distributed normally.

The mean values of the probability and impact of each risk were calculated. A risk matrix is considered as a good way to integrate possibility with impact (El-Sayegh, 2008). The risk matrix was proposed by the U.S. Air Force Electronic

Systems Centre (ESC) in 1995 (Fu et al., 2011) and is also used in various international standards such as ISO and IEC (Duijm, 2015). According to the study of El-Sayegh (2008), the risk matrix divides the risk significance into three levels, including high, moderate and low (shown in Figure 2.2).

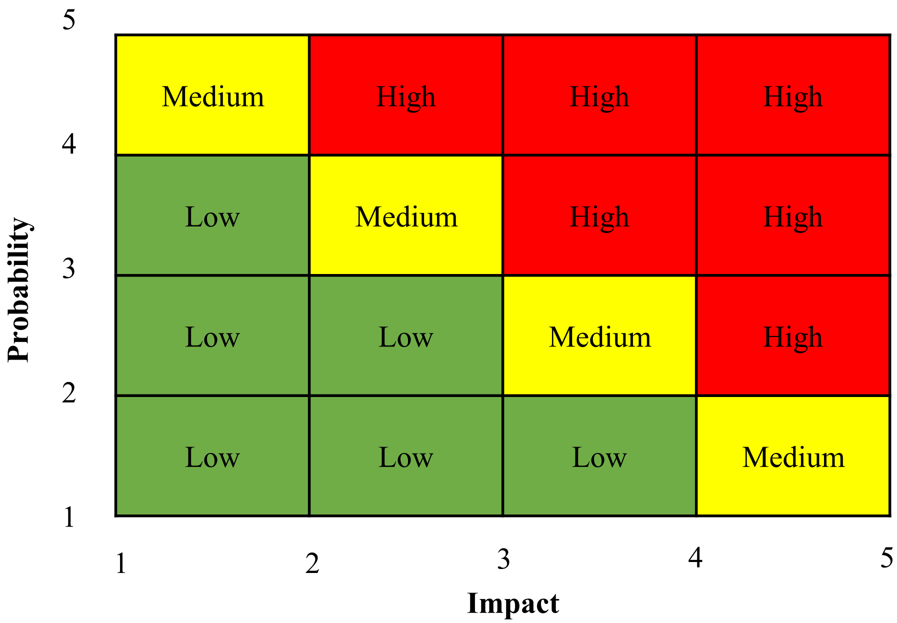

FIG. 2.2 Probability-Impact matrix

There are still some limitations to the original risk matrix in terms of risk rating. In general, the original risk matrix makes a ranking with many ties, which may lead to the sharing of the same level among some risks (Ni et al., 2010). The Borda count method was developed by ESC researchers to solve this problem. The Borda method can be introduced to the risk matrix in order to reduce the number of risk ties (Garvey and Lansdowne, 1998) significantly. It was also pointed out that the Borda method could be used to make a cross-check on the ratings of the risk matrix as well as to show what changes in possibility or severity were needed to mitigate a critical risk. Therefore, the Borda voting method needs to be applied to the risk matrix to rank risks more appropriately.

The Borda count for the risk j is calculated by

$$b_j = \sum_{k=1}^{2} (N - r_{jk}) \tag{1}$$

Where
N is the total number of risks
r_{jk} is the number of risks with higher scores than the risk j under the criterion k;
$j = 1, 2, \ldots, N$; $k = 1$ and 2

The Borda rank for risk is the number of risks with a higher Borda count than this risk. The higher the Borda rank, the more critical this risk is. The results of both the original risk matrix and Borda voting are considered in the overall risk rankings.

2.4 Results and analysis

Through the interviews, the process and stages of energy retrofit projects were adjusted to China's practical context (as shown in Figure 2.3). Figure 2.3 also summarizes the distribution of risks in each project stage and the stakeholders associated with each risk based on interviewees' descriptions. Most of the risks can be explained by TCT to some extent and are related to specific TCs (e.g. searching costs, monitoring costs, negotiation costs).

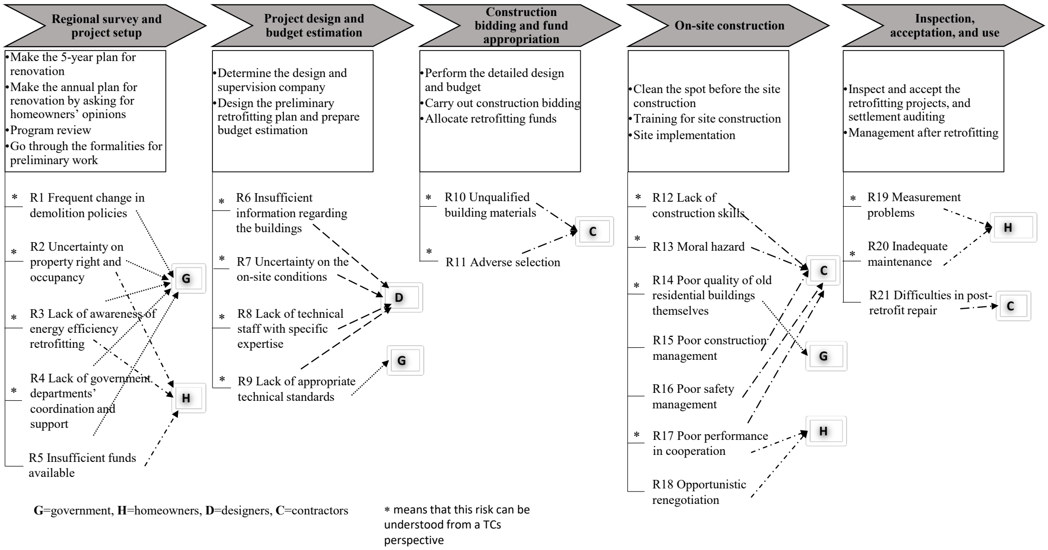

FIG. 2.3 Risks in the whole process of energy retrofit projects in practice (by the authors)

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Table 2.4 presents the statistical analysis for risks, including mean scores, the standard deviation (SD), the coefficient of variation (CV), and rankings of each risk based on means. SD and CV are the standard measures of data dispersion. Narrow SD and CV indicate stable and reliable data as well as the consistency of respondents' views on risk significance. The range of mean ± 1.64 SD is viewed as the consensus criterion for the items with a four-point Likert scale (Rogers and Lopez, 2002; West and Cannon, 1988). A wider range can be used for the consensus evaluation in this study with a five-point Likert scale. It is shown in Table 2.4 that all the SDs are below 1.27. Compared to SD, CV is a more standardized measure of statistics data dispersion and is calculated as SD divided by the mean. A CV below 0.5 is believed to indicate a reasonable and fair internal agreement (English and Kernan, 1976; Zinn et al., 2001). All the CVs listed in Table 2.4 are below 0.5.

TABLE 2.4 Statistical analysis for risks

	Probability				Impact			
	Mean	SD	CV	Rank	Mean	SD	CV	Rank
R1	2,91	1,22	0,42	15	3,01	1,33	0,44	18
R2	2,82	0,83	0,30	17	2,37	0,85	0,36	21
R3	3,94	0,87	0,22	1	3,66	0,51	0,14	6
R4	2,94	1,13	0,38	13	3,49	0,77	0,22	11
R5	3,09	1,18	0,38	11	3,30	1,13	0,34	13
R6	3,40	0,85	0,25	4	2,94	0,69	0,24	19
R7	3,16	0,91	0,29	10	3,12	0,98	0,31	16
R8	2,69	1,20	0,44	21	4,01	0,83	0,21	1
R9	3,18	0,87	0,27	9	3,70	0,97	0,26	4
R10	2,81	1,16	0,41	18	3,61	0,98	0,27	8
R11	3,09	0,87	0,28	11	3,30	0,85	0,26	13
R12	2,84	1,19	0,42	16	3,82	0,82	0,21	2
R13	2,81	1,25	0,44	18	3,07	1,27	0,41	17
R14	3,70	0,89	0,24	2	3,69	0,84	0,23	5
R15	3,31	0,86	0,26	7	3,66	0,62	0,17	6
R16	3,37	1,00	0,30	5	3,52	0,94	0,27	10
R17	3,36	1,01	0,30	6	3,75	0,84	0,22	3
R18	3,42	0,99	0,29	3	3,55	0,80	0,23	9
R19	2,75	1,11	0,40	20	2,64	1,06	0,40	20
R20	3,19	1,03	0,32	8	3,18	0,94	0,29	15
R21	2,93	1,22	0,42	14	3,37	1,04	0,31	12

Table 2.5 shows the level of each risk by considering the mean values of probability and impact. 12 risks have a high level of significance and the rating of 7 risks is medium. Only 2 risks are considered as low. Risk rankings based on the Borda method are also presented in Table 2.5. Borda voting is an extension of the risk matrix method and enables risks at the same or similar risk matrix levels to have different priorities.

TABLE 2.5 Overall risk significance based on risk matrix and Borda voting

Rank based on two methods	Risk	Probability rank	Impact rank	Risk rank based on Borda voting	Risk matrix
1	R3	1	6	1	High
1	R14	2	5	1	High
3	R17	6	3	3	High
4	R18	3	9	4	High
5	R9	9	4	5	High
6	R15	7	6	5	High
7	R16	5	10	7	High
8	R12	16	2	8	Moderate
9	R8	21	1	9	High
10	R20	8	15	10	High
11	R6	4	19	10	Moderate
12	R5	11	13	12	High
12	R11	11	13	12	High
14	R4	13	11	12	Moderate
15	R7	10	16	15	High
16	R10	18	8	15	Moderate
16	R21	14	12	15	Moderate
18	R1	15	18	18	Moderate
19	R13	18	17	19	Moderate
20	R2	17	21	20	Low
21	R19	20	20	21	Low

Risk rankings based on Borda method are largely consistent with risk ratings in the original risk matrix. The top seven risks in Borda method are labelled as the high level in risk matrix, and the last four risks are viewed as moderate and low levels. The differences mainly focus on the risks ranked in the middle. *Uncertainty on the on-site conditions* (R7) is at a high level based on the original risk matrix but has a low risk ranking through the Borda voting due to a relatively low ranking for its impact (16th). On the contrary, *Lack of construction skills* (R12) with a high ranking of risk impact (2rd) and a low score of risk probability (P<3) is at the moderate level in the risk matrix but is ranked ahead of some risks with a high level. Furthermore, although *Lack of government departments' coordination and support* (R4), *Insufficient funds available* (R5), and *Adverse selection* (R11) have the same ranking based on Borda voting, their risk levels are noticeably different: R5 and R11 are at a high level, but R4 is at a moderate level due to a relatively low score of its probability (P<3). Similarly, both *Insufficient information regarding the buildings* (R6) and *Inadequate maintenance* (R20) are ranked the 10th, but R6 is at the moderate level in the risk matrix and R20 is high due to a low score of R6's impact (I<3).

Table 2.5 combines the results of two methods to show the final risk rankings with the least risk knots. Following other studies (Wang and Qin, 2017; Zhang et al., 2018), the final rankings are mostly based on the results of the Borda method. Risk ratings in the original risk matrix are used to re-rank the risks that are given the same priority by the Borda method. For example, R20 is viewed to be more important than R6 due to R20's higher level in the risk matrix than R6.

A higher priority is given to the top-ranked risks in order to ensure more effective risk management with the least inputs. The top ten risks are chosen to represent the key risks, which is also in line with other similar studies (Tam et al., 2004; Zou et al., 2007). The ten risks are ranked in the top half of 21 risks and mostly at a high-risk level. Figure 2.4 presents the ten risks and the relevant work with TCs considerations. Two hypotheses are verified based on the analysis of project stages, stakeholders, and TCs, related to key risks. These key risks are scattered throughout the whole process of energy retrofit projects, especially at the design and on-site construction stages. Most of the key risks occur at the on-site construction stage and are related to homeowners and contractors. The key risks associated with homeowners are mainly caused by their negative attitudes towards retrofits in the early stage, cooperation in the execution phase, and maintenance after retrofitting. These risks lead the government, contractors, and even homeowners to bear more TCs. As the providers of construction service, contractors are the main actors in the process of on-site construction. Their technical competence and management performance greatly influence project objectives (e.g. quality and safety).

Similarly, designers are also the important technical staff in energy retrofit projects so that the risk with respect to professional abilities also has something to do with them. Correspondingly, these risks about contractors' and designers' competency cause an increase in the government's TCs. The key risks associated with government arise from their inadequate preparation for project selection and technical requirements, and involve their own TCs.

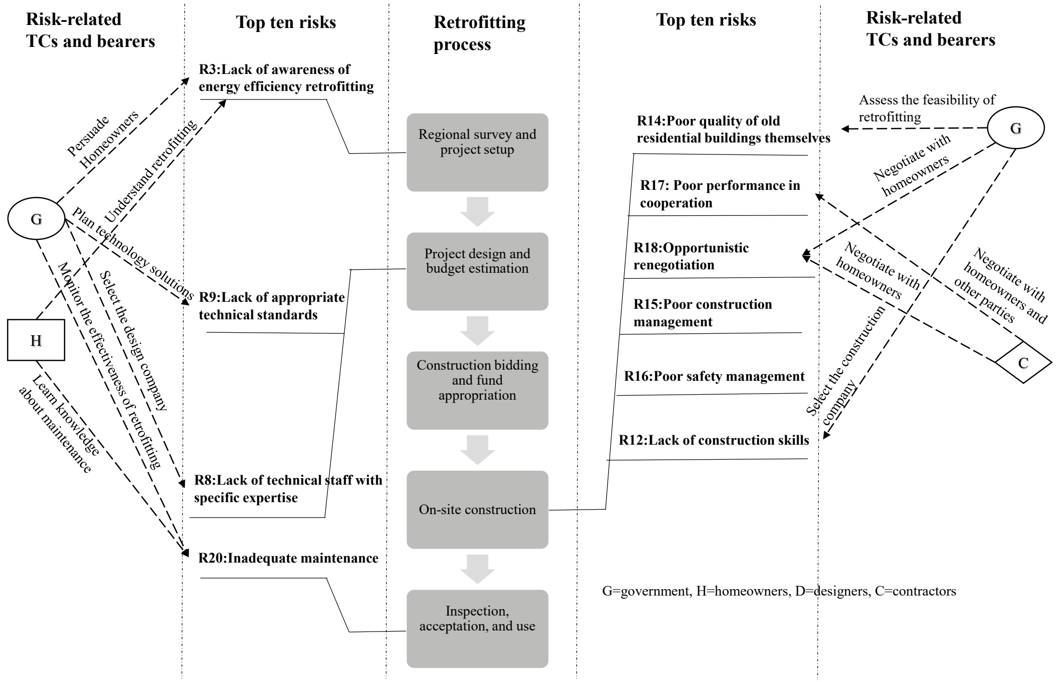

FIG. 2.4 Connections of key risks, project stages, TCs, and stakeholders (by the authors)

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2.5 Discussion

2.5.1 Focus of risk management from a stakeholder perspective: homeowners' participation and cooperation

Three of the four most critical risks hindering the implementation of energy retrofit projects in China are associated with homeowners. The implementation of energy retrofitting projects requires most homeowners' approval (more than 2/3) in an apartment building in China. It is common for homeowners that there is a lack of retrofit knowledge and information in China. The local government, therefore, needs to provide professional knowledge to raise their awareness. However, homeowners' attitudes towards retrofitting and their coordination during the on-site construction are also affected by the damages that retrofitting entails. For instance, homeowners are asked to demolish the illegal construction around the buildings and on the roof before on-site construction. That is similar to the international context in which homeowners need to understand the merits of energy retrofitting and should bear the costs and the destruction involved in retrofitting (Ürge-Vorsatz et al., 2012). In China, the local government needs to spend time negotiating with homeowners to demolish the illegal construction and even have to provide compensations in the form of money for homeowners. The Chinese government is the main investor of housing energy retrofitting projects, but in the Northern European countries, the lacking of funding for homeowners is seen as one of the main barriers to energy retrofit implementation (Itard and Meijer, 2008). Such a difference also leads to homeowners showing little concern about costs in China. It is more likely to result in homeowners' changeable opinions on what to be included in the retrofit package, or to raise additional demands that are not included in the original retrofit plans during the on-site construction process, thus disrupting its efficiency.

2.5.2 Key stage for risk management: on-site construction involving contractors and homeowners

Since most of the key risks are concentrated in the stage of on-site construction, more attention should be given to the contractor-associated risks in this phase in China's energy retrofit. This is consistent with the views of Fylan et al. (2016) that the most common risks during the on-site construction are usually associated

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with contractors. However, survey results show that the great importance of the risk related to contractors' competence is mostly due to its severe impacts and the probability of its occurrence is smaller than that of most risks. That is triggered by the technical limitation in the survey area. Suppose homeowners do not bear the expenses of retrofitting. In that case, a limited fiscal budget leads to only basic technology options, including external wall and roof insulation, energy-efficient windows, and indoor public space LED-lighting. Even in the northern area where energy retrofitting is developed better, energy-saving technologies in the local government-led projects are only limited to external thermal insulation and energy-efficient windows (Liu et al., 2015). These basic energy-saving technologies are mastered by many contractors fulfilling the qualification requirements, but the recognition of contractors' ability does not mean that their work performance can be recognized. The risks about construction management and safety management are still emphasized by survey respondents, which is also partly in line with by Fylan et al. (2016) attributing contractor-associated risks to their poor performance in installing retrofitting equipment and quality control.

Cooperation between stakeholders is also viewed as an essential risk factor in the Chinese context. Still, the difference from the international context is that the relevant risks are associated with both contractors and homeowners. During the process of on-site construction, cooperation risks are generally considered to occur, arising from disruptions between construction parties on-site, leading to a chaotic construction process (Rovers, 2014). Such chaos brings more burdens to homeowners because the buildings are still inhabited during the construction. The troubles (e.g. dirt and stress) are the leading causes of homeowners' negative attitudes towards energy-saving measures (Zundel and Stieβ, 2011), further leading them to be more reluctant to cooperate. In fact, poor cooperation is more likely to be caused by homeowners since multi-family building typology is dominant in China. Multi-family building residents are more inclined to only consider their apartment unit as their home rather than the whole building, as shown by Miezis et al. (2016). Some residents worry about whether certain construction activities undermine their own interests, causing them to raise objections and question or challenge some construction works.

2.5.3 Main sources of TCs associated with key risks: information, negotiation and monitoring

Information costs are related to most of the key risks in energy retrofit projects in China. Given their unprofessional background, homeowners in China need to bear these costs in order to know more about the advantages and disadvantages of retrofits, the reliability of skilled service providers, and even how to undertake the maintenance of retrofit works. Indeed, building owners are generally considered the bearer of information costs in the international context (Kiss, 2016; Matschoss et al., 2013). Hein and Blok (1995) also attributed these higher information costs to homeowners' insufficient access to knowledge of energy efficiency technologies. However, as the investor and leader of energy retrofits, the government is the main bearer of information costs at an early stage in China. The local government undertakes more work involving information searching and assessment to set up technical guidance for retrofit solutions and then judge whether design and construction companies are competent for retrofit projects when selecting partners. Beyond that, the Chinese government is also responsible for project selection, and is thus involved in searching for the building information on structure type and stability to make sure that the existing building condition can withstand the stresses from retrofitting.

Negotiation and monitoring costs are also associated with key risks in energy retrofit projects. The local government in China needs to pay more in terms of negotiation costs in the early phase to introduce the concept of energy retrofit to homeowners, in order to persuade and encourage more homeowners to be involved in retrofit projects. Besides, negotiation costs in China's implementation phase arise from the need to undertake cooperation and renegotiation with homeowners due to their lack of understanding of construction activities and the unplanned retrofit requirements. By contrast, it is more general in the international context to connect negotiation costs with the coordination among construction parties (Bleyl-Androschin et al., 2009; Mundaca, 2007). The uncertainty on post-retrofit maintenance incurs more TCs for monitoring the usage and maintenance of energy-efficient technologies. In fact, monitoring costs are also widely considered to be related to measurement and verification (Mundaca, 2007; Mundaca T et al., 2013). To achieve good performance of energy-saving measures, buildings maintenance and even homeowners' usage and occupancy behaviours in public space are monitored after retrofitting to keep these technologies in good condition.

2.6 Conclusion

Energy retrofit of residential buildings has been recognized as an important measure to promote energy conservation and emission reduction as well as to improve the quality of people's lives. For effective risk management, it is necessary to understand the key risks in the whole process of retrofit projects and its stakeholders. This study has identified 21 risks with TCs considerations in the entire process of retrofitting projects in the HSCW zone of China and ranked them based on Borda voting and risk ratings in the original risk matrix. Two hypotheses are supported by the results. It is confirmed that homeowners and contractors are the key stakeholders associated with seven of ten key risks and on-site construction is the key stage at which most of the key risks are concentrated. TCs are induced by different stakeholders in different stages and can help understand most risks.

Homeowners are related to the most critical risks at the stage of on-site construction and even in the whole process. Their low awareness, poor cooperation, and opportunistic behaviours have negative impacts on project initiation and execution. The contractor is the other key group during the on-site construction due to the risks of their professional expertise, construction management, and safety management. Most key risks are relevant to TCs, including information, negotiation, and monitoring costs. Information costs scattered throughout the whole process are the most prominent. Such costs are affected not only by the selection of government on technical standards, retrofit projects, and technical staff, but also by homeowners' lack of understanding of retrofit merits, the reliability of construction partners, and what, when, and how to do maintenance. Even in the original risk matrix, information costs are still dominant and are associated with most of risks rated at a high level.

TCs, especially information costs, exist widely in energy retrofitting projects in China and other countries, and can also enrich the understanding of risks in the international context. In China, information costs are involved in government's work at the early stage of retrofitting projects and also induced by homeowners' insufficient knowledge. Homeowners bear more information costs in some other countries where retrofits of private dwellings are decided and funded by owners themselves. Given the universality of information costs in retrofitting risks, it is suggested to enhance information disclosure and provision in retrofitting projects in China and worldwide. First, information provision on energy retrofit technologies and schemes at the early stage of projects reduces the change of plans and minimizes homeowners' dissatisfaction in the subsequent phases in China. Second, homeowners' trust in on-site construction can be enhanced by increasing access to more information on technical staff, further improving their performance in cooperation. Third, knowledge of maintenance is conducive to homeowners' involvement in maintaining good performance of retrofitting measures. Fourth, information disclosure on designers and constructors' technologies and ability can facilitate the rational decision-making of the government in China and homeowners in the international context.

The empirical cases and data were conducted on retrofitting projects in four cities in Anhui province to showcase the common retrofitting measures and practices. Only the standard and basic energy-saving technologies were considered in these selected case projects. For future research, more case projects can be collected to exemplify the retrofitting projects with a better pool of representation for the HSCW zone in China to withdraw more broad conclusions on the retrofitting processes and stakeholders' experiences in risk content.

TOC

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3 Stakeholders' Risk Perception:

a Perspective for Proactive Risk Management in Residential Building Energy Retrofits in China

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ABSTRACT

The implementation of energy retrofit of residential buildings faces many risks around the world, especially in China, leading to low retrofit progress. Stakeholders' proactive risk management is the key to the smooth implementation of retrofit projects but is normally affected by risk perception. Perceived risks instead of real risks are the motivators of their proactive behaviours. This study aims to understand and address the present risk perception of stakeholders in order to drive effective proactive risk mitigation practices. Based on a risk list identified through a literature review and interviews, a questionnaire survey was then made to analyse and compare different stakeholders' perceptions of each risk by measuring the levels of their concern about risks. It is validated that all the stakeholder groups tend to proactively mitigate risks perceived highly. Proactive risk management of risk-source-related stakeholders deserves more attention and responsibility sharing with transaction costs (TCs) considerations contribute to the enhancement of risk perception. More responsibilities of construction quality and maintenance taken by the government and contractors should be clarified, and the government should be also responsible for assisting design work. Effective information is beneficial to the decrease in homeowners' risk perception that can motivate their initiative of cooperation.

KEYWORDS

Energy retrofits; Risk perception; Proactive risk management; Stakeholder behaviours; Transaction costs

3.1 Introduction

Building energy use has become the main driver for the growing worldwide energy consumption and CO_2 emissions. Worldwide, 28% of CO_2 emissions and 30% of final energy consumption were attributed to the building sector in 2018 (IEA, 2019a). In particular, the final energy consumption of residential buildings accounts for over 70% of the global total (IEA, 2019a). The global continuous growth in building end uses is mainly driven by heating, lighting and household cooking (IEA, 2018). The most striking increase in energy intensity per unit of floor area is related to space cooling with a growth of nearly 10% from 2014 to 2018 (IEA, 2019b, c). In China, building energy consumption was 899 million tonnes coal equivalent (tce) and CO_2 emissions was 1.96 billion tons in 2016, accounting for 20.6% and 19.4% of national total quantity, respectively, in which energy consumption and carbon emissions of urban residential buildings share 38% and 41%, respectively (CABEE, 2018). Meanwhile, China has also experienced a rapid growth of energy demand for space cooling over the past two decades, increasing at 13% per year since 2000 and even reaching 50% of peak electricity demand in recent summers, which leads to a large increase in CO_2 emissions (IEA, 2019d). Sustainable buildings are the key factors to mitigate such environmental impacts, and this goal can be achieved by replacing inefficient building elements with more efficient ones (Vlasova and Gram-Hanssen, 2014). Existing building retrofitting has been identified by the GlobalABC Global Roadmap as one of the key priorities for reducing the impacts of buildings on energy and climate (UNEP, 2016). Canada highlighted the use of new retrofit codes in building retrofitting in the updated nationally determined contribution (NDC) in 2017 (IEA, 2018). In 2018, the revised Energy Performance of Buildings Directive (EPBD) required all EU member states to implement long-term retrofitting strategies in order to achieve a highly efficient and fully decarbonised building stock by 2050 (IEA, 2018). Likewise, China viewed residential building retrofitting in both the northern region and the hot summer and cold winter (HSCW) zone as one of the main tasks for energy conservation and emission reduction in the latest plan in 2017 (MOHURD, 2017).

Efforts has been made to improve the energy efficiency of residential buildings in China. The total area of urban residential buildings by 2015 in China was 24.8 billion m^2, in which energy-efficient buildings accounted for more than 40% (CABEE, 2017; MOHURD, 2017). These achievements are mainly attributed to China's mandatory standards for building energy efficiency, and almost all new buildings were constructed in accordance with such standards during the period of the 12th Five-Year Plan (2011-2015) (MOHURD, 2017). By contrast, the development of energy retrofitting of residential buildings is relatively slow. Since 2006, residential buildings have been highlighted as a key potential area for energy savings through energy efficiency improvement (GOSC, 2011; NDRC, 2006). The total area of urban residential energy retrofitting was about 1.2 billion m^2 by 2015 and was less than 1.6 billion m^2 by 2018 nationally. In particular, the northern region is the main undertaker of these retrofitting projects, and there is unbalanced development of energy retrofits in different regions in China. During the 12th Five-Year Plan period, 990 million m^2 of retrofit projects were completed in the northern region but only 70.9 million m^2 in the hot summer and cold winter (HSCW) zone (MOHURD, 2017). In fact, urban existing residential building stock in the HSCW zone covered an area of almost 6 billion m^2 in 2012 (Liu et al., 2017). Moreover, building energy efficiency in this region started late and developed slowly compared to cities in the northern region. In the past several years, heavy use of heating facilities resulted in a 575-fold increase in the residential heating energy consumption in the HSCW zone, which also is a major factor driving a rapid growth of residential energy consumption in China (Lin et al., 2016). It is therefore necessary to accelerate the implementation of energy retrofitting of residential buildings in the HSCW zone of China.

The implementation process of energy retrofits is faced with many risks especially in China due to the interactions of the involved various stakeholders. The risks in this study are defined as future and uncertain factors/events exerting a negative influence on project performances (e.g., costs, quality, organization, and management). Central and local governments, heating enterprises, property rights units, residents, energy-saving service firms, planning and design units, property management units, material and equipment suppliers, and construction and supervision units are viewed as the stakeholders of residential retrofit projects in China (Bao et al., 2012; Lu et al., 2014). In China, housing is generally privatized, and the property owners of a single building are dispersed among tens or even hundreds of households, which leads to the great probability of disagreement among these homeowners on retrofitting (Lv and Wu, 2009). Moreover, different personal circumstances among homeowners in terms of occupations, education levels, lifestyles and income levels may also give rise to the differences in the satisfaction and acceptance in retrofit technology, further resulting in the possibility of homeowners' dissatisfaction as well as misuse and disruption of installed technology (Liu et al., 2015). In addition to hundreds of homeowners, the government at all levels and different departments are also involved in the retrofit projects (Lv and Wu, 2009). As a result of more stakeholder interactions in energy retrofit projects, the whole process of such projects is more complicated than that of conventional projects (Klotz and Horman, 2009; Liang et al., 2015; Liang et al., 2017). In particular, the lack of a joint system for government departments at the high levels in China is likely to lead to poor coordination (Lv and Wu, 2009).

Stakeholders' proactive risk management is an approach to make a response plan in advance of the occurrence of a risk event, and also contributes to a smoother project process. The stakeholder is one of the primary sources of risks in projects (Skelton and Thamhain, 2006; Ward and Chapman, 2008). Stakeholders, through their work and behaviours, pose risks but are the most primary resources for risk mitigation (Skelton and Thamhain, 2006). Stakeholders have capabilities to proactively mitigate risks associated with them from the angles of risk probability or impact, which is key to risk management (Xia et al., 2017). Proactive risk management was viewed by Arrow (2008) as a more practical way towards project objectives. Smith and Merritt (2002) also believed that proactive risk management could effectively control uncertainty. Uncertainty is one of the primary transaction characteristics and also increases transaction costs (TCs) in the transaction process (Sutcliffe and Zaheer, 1998). TCs appear throughout the whole process of energy retrofit projects and originate from due diligence, negotiations, and monitoring (Kiss, 2016). When TCs are too large, the exchange, production, and economic growth would be inhibited (North, 1986). Proactive risk management, an effective manner of controlling uncertainty, can lower TCs and thereby eliminate the barriers to energy retrofit implementation for a smooth retrofit process. However, stakeholders' proactive behaviours have not been considered by studies on energy retrofits of residential buildings as risk mitigation measures. The previous studies tended to analyse risks from the perspectives of energy efficiency gap and investment benefits (Bao et al., 2012; Biekša et al., 2011; Caputo and Pasetti, 2015; Dahlhausen et al., 2015; Li, 2009; Lo, 2015) and viewed risks as the basis for the selection of retrofit solutions (Heo et al., 2012; Rysanek and Choudhary, 2013). Risk mitigation focuses on the development of energy-savings insurance to transfer risks of investors (Mills, 2003; Mills et al., 2006). These measures aim to safeguard investors' interests rather than to eliminate the barriers to the smooth implementation of the whole energy retrofit process.

Stakeholders' proactive behaviours for risk mitigation are generally aimed at their perceived risk. The connections between risk management and project success are dependent on three elements: stakeholders, their behaviours, and their risk perception (De Bakker et al., 2010; Kutsch and Hall, 2009). Indeed, the contributions of risk management to success mostly result from the impacts of risk perception on stakeholders' behaviours, namely that stakeholders adjust their behaviours according to their perception of risks (Cooke-Davies, 2001; Weick and Sutcliffe, 2001). Risk perception is a kind of subjective evaluation of risks by stakeholders and is based on the type of risk, personal experience, beliefs, attitudes, and culture (Pidgeon, 1998; Rohrmann, 2008). Stakeholders' perception of risk is based on the simplified decision-making process rather than real situations, and different culture also leads to their differences in subjective rationality and further

TOC

in risk perception (de Camprieu et al., 2007). Differences and contradictions in risk perception among different project stakeholders result in the misunderstanding and conflicts of risk mitigation practices (Bryde and Volm, 2009). Uncertainty avoidance is the core principle of stakeholders' behaviours (Ketokivi and Mahoney, 2016). If a potential risk is perceived by stakeholders to be high, they will take measures to mitigate it (Mañez et al., 2016). However, these stakeholders' actions aiming to mitigate risks produce TCs. TCs, in turn, affect stakeholders' behavioural selection. Transaction cost is an essential factor when transaction parties make trading decisions (Kissell, 2013). Stakeholders themselves have motivations to economize on TCs to maximize their own benefits. High TCs can be the barriers to stakeholders' proactive behaviours for risk mitigation. As with individuals' behaviours, TCs incurred by these behaviours are also subjective (Chiles and McMackin, 1996). In effect, stakeholders who voluntarily bear high TCs tend to expect higher benefits (Archibald and Renwick, 1998). Such behavioural conflicts among different stakeholders resulting from different risk perceptions and TCs may render those bearing high TCs unable to obtain the benefits as expected, which would lead to the dissatisfaction of some stakeholders and further influence the smooth implementation of retrofit projects.

Risk perception can motivate stakeholders' proactive risk management, which is the key to the smooth implementation of energy retrofit projects. The differences in risk perception among different stakeholders lead to the contradictions of risk mitigation practices, and TCs play an important role in stakeholders' behavioural conflicts arising from contradictions of risk perception. This study aims to analyse and address different stakeholders' perceptions of risks in order to motivate stakeholders' initiative of effective risk management. This study first establishes a risk list through both a literature review and interviews to connect the risks in the whole process of energy retrofit in China with the main stakeholders. Interviews are also made to explore stakeholders' proactive behaviours for risk mitigation in practice. A questionnaire survey is then conducted to explore and compare different stakeholders' perceptions of each risk by measuring the levels of their concern about risks. A validation is conducted to link high levels of risk concern with proactive risk management. Finally, some suggestions with TCs considerations are given under different risk perceptions of stakeholders to drive the effectiveness and feasibility of proactive risk mitigation practices.

3.2 Literature review

3.2.1 Risk perception

There is no agreement about the measurement of individuals' risk perception, and risk perception is regarded as a complex construct (Helgeson et al., 2012). It is significant for studies on risk perception to choose the proper risk dimensions according to the study purpose (Sjöberg, 1998). Different items have been used by previous studies to help shape risk perception, including cognitive, emotional, societal, and subconscious factors (Dobbie and Brown, 2014; Drinkwater and Molesworth, 2010; Hillson and Murray-Webster, 2004; Ulleberg and Rundmo, 2003). In particular, cognition and emotion are the most common and are generally viewed as the main dimensions of risk perception. The cognitive dimension means the perceived likelihood and severity of risks, while the emotional dimension refers to the feelings of worry and anxiety (Dunwoody and Neuwirth, 1991). Sjöberg (1998) stated that risks cannot give rise to emotional perception but cognitive. It was also highlighted that risk perception required a more rational judgment and people seldom determined their judgment of risks based on emotions. However, Hartono et al. (2014) argued that decision-makers tend to make decisions based on their intuition and feelings rather than the normative theory (e.g., the probability and consequences of risks). Indeed, some studies on cognition also emphasized that individuals' cognitive ability is limited due to their bounded rationality (Jones, 1999; Kahneman, 2002). It is believed that emotions (e.g., worry and fear) can motivate people to self-protect (Bao et al., 2012; Biekša et al., 2011; Caputo and Pasetti, 2015; Dahlhausen et al., 2015; Li, 2009; Lo, 2015). In short, both cognitive and emotional factors should be considered in the judgment process of risk perception (Böhm and Brun, 2008).

The concern is a concept involving both cognitive and affective dimensions and can be used to measure stakeholders' perceptions of risks. Dunwoody and Neuwirth (1991) viewed concern as an affective judgment of risk perception, but concern was regarded by Rundmo and Iversen (2004) and Brown et al. (1983) as a more cognitive notion in risk perception. Likewise, Rundmo (2002) thought that concern is one aspect of effect but is associated with cognitive risk perception. Worry is generally viewed as an active emotional state and is close to adaptive behaviours for risk mitigation (Smith and Leiserowitz, 2014; van der Linden, 2014). Concern can be seen as those worried and upset topics and is closely related to actionable worry (Anthony Cox Jr, 2007). Concern itself can be used to affect people's behaviours, and certain levels of concern can motivate people to take actions to handle risks (Vanlaar et al., 2007; Vanlaar et al., 2008). In fact, the concept of concern has been adopted by some studies to measure risk perception. Wildavsky and Dake (1990) evaluated the perception of technical, environmental, social, and economic risks based on a series of people's concerns. Similarly, how much people have concern about risks is also used to refer to the levels of their risk perception (Fisher and Robson, 2006; Park et al., 2001; Siegrist et al., 2005). Based on the Gallup environment surveys in which respondents were asked the degree of their concern about economic and social problems, Xiao and McCright (2012) formed the measurement framework of risk perception. Mou and Lin (2014) also used the level of risk concern to measure the public's perceived level of risks related to food supply and handling. As a result, this study also applied stakeholders' concerns about risks to the measurement of risk perception.

3.2.2 Behaviours related to risk perception

The role of perception in precautionary and protective behaviours has been highlighted in many studies. There is an assumption in the protection motivation theory that individuals' perception of the severity of a threat and the effectiveness of mitigation measures is the basis of their protective behaviours (Rogers and Prentice-Dunn, 1997). The protective action decision model also points out the roles of perception in protective behaviours and postulates that risk perception has impacts on decision making on mitigation measures (Lindell and Perry, 1992; Lindell and Prater, 2003). In addition, the prospect theory also aims to predict the individuals' behavioural responses to different risk perceptions (Kahneman and Tversky, 2013). This theory argues that there is a negative connection between risk perception and risk-taking behaviours (e.g., risk-averse and risk-seeking) (Sitkin and Pablo, 1992). Rogers (1983) stated that an individual's perception of risks facilitated their engagement in protective behaviours. Risk perception contributes to individual perception of their responsibility on environment protection (Iversen and Rundmo, 2002). The individuals with high perception of environmental risks have stronger intentions to take environmentally friendly actions (Baldassare and Katz, 1992; Toma and Mathijs, 2007). It has been found in the studies on disasters and hazards that risk perception can predict warning responses of reducing the losses from disaster risks (Lindell and Perry, 2012). People with high-risk perception are more likely to take preventive actions than their counterparts with low-risk perception (Ruin et al., 2007; Vinh Hung et al., 2007). Adams (1995) described the relationships between safety perception and risk status and pointed out that the increase in safety perception could motivate individuals to have compensation behaviours to lower risk levels. Loosemore et al. (2012) applied this logic to the construction field in order to drive people to adjust their behaviours for risk mitigation. The differences in risk perception among different groups lead to the diversity of their practices in risk mitigation (Fung et al., 2005). In a short, risk perception is an important motivator of stakeholders' proactive risk management.

3.2.3 Transaction costs (TCs) considerations

TCs are different from production costs and are the economic equivalent of friction in physical systems (Williamson, 1985). TCs are influenced by three main transaction dimensions, including asset specificity, uncertainty, and frequency (Williamson, 1991). Asset specificity is usually defined as "durable investments that are undertaken in support of a particular transaction" (Williamson, 1985). Uncertainty is classified as environmental and behavioural uncertainty. Environmental uncertainty means that transaction circumstances cannot be specified beforehand, leading to an increase in time and processes for monitoring and controlling against environmental diversity (Williamson, 1979). Behavioural uncertainty refers to transaction partners concealing and distorting information (Williamson, 1985).

Stakeholders need to bear high TCs when involved in the interactions for risk mitigation (Ward and Chapman, 2008), such as the costs of learning knowledge, collecting information, supervising construction work, and exploring new technical schemes. Preventive behaviours originating from high-risk perception were based on low costs of behavioural change (Janz and Becker, 1984). People who have positive attitudes towards proactive behaviours may not be able to put such behaviours into practice due to the lack of resources (Ajzen, 2011). In fact, risk perception is associated with people's ability understand and respond to risks, and objective risk attributes (Gregory and Mendelsohn, 1993; Sitkin and Weingart, 1995). Probability and impact are the main attributes of risks, which have the features of uncertainty. From a TCs perspective, asset specificity in risk management service transaction can be considered as the capability of different transaction parties for risk management (Jin and Doloi, 2008). In addition, the degree of people's concern about risks and their experience in risk management have important impacts on their ability of information acquisition and processing, which also further affects their risk preparedness behaviours (Su et al., 2015). That also means that proactive risk management practices related to risk perception are restricted by uncertain information and specified assets with respect to stakeholders' experience.

Proactive risk management involves stakeholders' participation, risk management commitment, and initiating risk management processes early in the project (Arrow, 2008). Proactive risk management can be regarded as the activities of stakeholders' establishing and managing committee, and the success of proactive risk management efforts depends on the commitment of stakeholders' risk management. In the Chinese context of residential energy retrofit, risk perception is concerned with environmental uncertainties about stability of retrofit policy, ambiguity of retrofit performance, complexity of design, complexity of construction, and even maturity of retrofit market in terms of technology, competence, and materials. Behavioural uncertainty is based on stakeholders' opportunism, and commitment can help prevent opportunism (Williamson, 1983; Williamson, 1975). Behavioural uncertainty in risk management transaction is related to stakeholders' commitment to risk management (Jin, 2009). Asset specificity and uncertainty incur more TCs in risk management service transaction and thereby prevent stakeholders from undertaking the proactive risk management practices.

Based on transaction costs theory (TCT), the major characteristics of proactive risk management affected by risk perception include: (1) stakeholders' experience and ability in terms of risk management, which are the main specified assets of proactive risk management; (2) environmental uncertain factors related to proactive risk management; (3) stakeholders' commitment to risk management, which corresponds to behavioural uncertainty.

3.3 Research methodology

The national documents provide a generic scope for retrofitting objects of residential buildings in China. In general, priority for energy efficiency retrofitting is given to the residential buildings with good seismic and structural safety performance and poor thermal performance of the building envelope (MOHURD, 2013). These buildings were constructed with few energy efficiency measures, and residents need to consume a great deal of energy to improve the indoor thermal environment. At present, the comprehensive retrofitting mode for residential quarters is encouraged (MOHURD, 2017). In this pattern, there are not only energy efficiency measures, but also those regarding environment improvement, infrastructure renovation, structure reinforcement, etc.

There are some differences in the scopes of retrofitting objects among different provinces in the HSCW zone, but old residential quarters are the common focus of energy retrofitting. These residential quarters have been generally used for at least a dozen years, and consist of several multi-story apartment buildings. This study takes Anhui province in the HSCW zone of China as the object of empirical analysis. There are five basic criteria for the retrofitting scope in Anhui province: residential quarters were constructed and delivered before 31st December in 2000; the gross floor area is not less than 5000 m^2; these quarters are not involved in other renovation plans (e.g., urban renewal, shantytown renovation, and urban village renovation); the lands of these residential quarters are owned by the nation; and these apartment buildings are composed of complete residential packages including living rooms, bedrooms, a kitchen, a bathroom, etc.

3.3.1 Literature review

This study conducted a systematic review to identify the theoretical risks. Articles considered in the literature review were related to energy retrofitting of residential buildings and published in international scientific journals up to March 2018. Google Scholar was the main database for the literature search. Several keywords used for searching articles were classified as three categories as follows: (1) “energy retrofitting” and “energy renovation”; (2) “residential buildings” and “housing” (3) “risks”, “uncertainty”, and “barriers”. This study selected one keyword from each category in each search and combined them to search articles, such as “energy retrofitting”, “housing”, and “risks”.

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3.3.2 Interview

The risks were identified through literature review and face-to-face interviews in China. Based on a field survey, this study divides the main stakeholders in retrofit projects into four groups, namely homeowners, governments, designers and contractors. Interviewees were directly related to energy retrofitting in Anhui province in China and were mostly from energy retrofit cases in three cities, including 10 government officials, 4 designers, 4 on-site construction managers, and 4 homeowners. In these projects, doors and windows were replaced by those with higher levels of insulation, and new thermal insulation materials were also used to strengthen the insulation of walls and roofs.

The government representatives were selected from four levels of government departments of housing and construction, including the provincial government, the municipal government, the district government, and sub-district administrative office. Except for the provincial government, the interviewees from the other three levels of government were almost always involved in all stages of the energy retrofitting projects in practice. For this reason, government interviewees are not only familiar with all processes in retrofitting projects but also are qualified for the identification of risks existing in each stage. In particular, interviewees from sub-district administrative offices keep in close touch with contractors and homeowners, which also enables them to know something about the risks associated with these two stakeholder groups.

The industry stakeholder representatives were the chief leading members in charge of the retrofitting design and construction in practice. All of them were involved in three pilot retrofitting projects in Anhui province. As the main stakeholder groups, these interviewees from design and construction companies have a more comprehensive view of the risks occurring at the stages of design and on-site construction and can provide more detailed information about these risks.

The homeowner representatives were from three pilot projects and were also the members of either homeowners' committees or neighbourhood committees in the local residential quarters. There are 612 households in total in these three projects. The homeowners' committee acts on behalf of all the homeowners in a residential quarter. Members of homeowners committees gathered homeowners' requirements and suggestions in the course of retrofitting implementation, and reported them to other retrofitting parties. Neighbourhood committees played the similar role in the retrofitting projects. Two interviewees were both neighbourhood committee staff and homeowners. There are no homeowners' committees in some renovated residential quarters, and members of neighbourhood committee are therefore responsible for information transmission in practice. As members of homeowners committees and neighbourhood committees, these interviewees have a better understanding of the potential project risks than the ordinary homeowners.

These interviewees introduced the work and responsibilities of their own stakeholder groups and elaborated on the problems they encountered and their concerns in the course of project implementation. Meanwhile, they were also asked about some proactive measures taken in practice for risk mitigation.

Interviewees' views were taken into consideration to adjust the theoretical risks to the Chinese context. The risk list is shown in Table 3.1, in which 21 risks exist in the whole process of residential energy retrofit projects in China.

TABLE 3.1 Risks in the whole process of energy retrofit projects in practice

Phases	Risks	Literature Sources
Regional survey and project setup	R1: Frequent change in demolition policies	
	R2: Uncertainty on property right and occupancy	
	R3: Lack of awareness of energy efficiency retrofitting	(Biekša et al., 2011; Caputo and Pasetti, 2015)
	R4: Lack of government departments' coordination and support	(Bao et al., 2012)
	R5: Insufficient funds available	(Bao et al., 2012; Biekša et al., 2011; Caputo and Pasetti, 2015; Dahlhausen et al., 2015; Li, 2009; Lo, 2015)
Project design and budget estimation	R6: Insufficient information regarding the buildings	(Mitropoulos and Howell, 2002)
	R7: Uncertainty on the on-site conditions	
	R8: Lack of technical staff with specific expertise	(Boutaud et al., 2011; Ferreira and Almeida, 2015; Hallikas et al., 2004; Mills et al., 2006; Olgyay and Seruto, 2010)
	R9: Lack of appropriate technical standards	
Construction bidding and fund appropriation	R10: Unqualified building materials	
	R11: Adverse selection	
On-site construction	R12: Lack of construction skills	(Boutaud et al., 2011; Ferreira and Almeida, 2015; Fylan et al., 2016; Hallikas et al., 2004; Olgyay and Seruto, 2010; Sunikka-Blank and Galvin, 2012)
	R13: Moral hazard	
	R14: Poor quality of old residential buildings themselves	
	R15: Poor construction management	(Fylan et al., 2016)
	R16: Poor safety management	
	R17: Poor performance in cooperation	(Rovers, 2014)
	R18: Opportunistic renegotiation	
Inspection, acceptation, and use	R19: Measurement problems	
	R20: Inadequate maintenance	(Boutaud et al., 2011; Mills, 2003; Mills et al., 2006; Olgyay and Seruto, 2010; Walker et al., 2014)
	R21:Difficulties in post-retrofit repair	

3.3.3 Questionnaire survey

According to the above risk list, a questionnaire survey was conducted to explore the concern of different stakeholder groups on different risks in the whole process of energy retrofit projects in China. This questionnaire comprised two sections: (1) background information of the respondents; (2) respondents' concern about different risks. In the second part of this questionnaire, a Likert scale of 1–5 was used to measure the level of stakeholders' concern about a risk from their subjective point of view (1 = not concerned, 2 = a little concerned, 3 = neutral, 4 = somewhat concerned, 5 = very concerned).

The questionnaires were distributed via personal delivery to increase the response. The questionnaires were targeted at people representing four different stakeholder groups including governments, homeowners, contractors, and designers. A total of 450 questionnaires were delivered to the respondents. A total of 172 valid questionnaires were collected from 44 government officials, 55 homeowners, 38 construction managers, and 35 designers, respectively. This rate is 38.2 % and is acceptable and common.

These respondents have been involved in the energy retrofitting projects in five cities of Anhui province in China. Hefei, the capital of Anhui province, has been listed as the pilot city of energy retrofitting of residential buildings in the HSCW zone of China in 2012. Since 2016, the provincial government has encouraged applying energy efficiency measures to the province-wide existing residential buildings. Anhui province operated more than 300 energy retrofitting projects by 2019. The government respondents, as the decision makers and executors, were involved in all the retrofitting projects in the city where they work. The respondents from the design and construction companies were also the participants of the completed retrofitting projects. Moreover, these design companies generally undertake the design work of most energy retrofitting projects in their own cities.

All the homeowners involved in this questionnaire survey were related to the comprehensive energy retrofitting projects that have been completed. In fact, retrofitting items (e.g., exterior windows, sunshade, roof, exterior wall, etc.) were only partially executed in the majority of energy retrofitting projects in Anhui province and even in the HSCW zone. There were only three comprehensive energy retrofitting projects in Anhui in 2017, and these respondents are some of the owners of the three retrofitting projects. These homeowners had more exposure to other participants and difficult retrofitting work due to the comprehensiveness of retrofitted building items. The complexity of comprehensive projects also enables them to have a more holistic perception of project risks.

Comprehensive energy retrofitting is the major trend and is being advocated by more governments. The views of these respondents can also provide lessons for future retrofitting projects.

3.3.4 Data analysis method

The data collected from questionnaires were analysed from three aspects of the comparison of risk concern within each stakeholder group, the comparison of risk concern among all stakeholder groups, and the comparison of risk concern within different pairs of groups. First, the degree of concern on all risks in each stakeholder group was measured by mean scores, which can investigate the rankings of risks in terms of stakeholders' concern. Second, one-way ANOVA was applied to compare the mean scores of all the stakeholder groups in order to find out the main differences in stakeholders' concern about all risks from an overall perspective. Levene's test for equality of variances was applied to assess the assumption of homogeneity of variance that there was no difference in the variances among all the groups prior to one-way ANOVA. Variances among the four groups were proved to be equal if the significance value (p-value) was over 0.05, and the concern among all of groups could be compared based on the p-value of one-way ANOVA. If not, Welch's test was used to adjust the results of one-way ANOVA, and a p-value of less than 0.05 also served as a standard to measure the significance of differences. Welch's test is considered more reliable when variances are unequal (Derrick et al., 2016; Ruxton, 2006). Third, for those risks with significant differences among all the four groups, Scheffe's test or Games-Howell test were adopted to compare risk concern within different pairs of groups according to the results of the abovementioned Levene's test, and the threshold value p was also 0.05. Scheffe's test is the most common for equal variances, and there is no need for each group to contain the same sample size. This test can also be used to make all possible comparisons among group means, not just planned pairwise comparisons. Games-Howell test is suitable when the variances are unequal and also does not assume the same sample size among all of groups. Moreover, this test is appropriate for the results of Welch's test.

3.4 Survey results and analysis

3.4.1 Comparison of risk concern within each stakeholder group

The degrees of concern on all risks of each stakeholder group are measured by mean scores, and the standard deviation (SD), the coefficient of variation (CV), and rankings are also summarized (see Table 3.2).

TABLE 3.2 Mean scores of concern of different stakeholder groups on risks

	Government				Homeowners				Contractors				Designers			
	Mean	SD	CV	Rank	Mean	SD	CV	Rank	Mean	SD	CV	Rank	Mean	SD	CV	Rank
R1	4.07	0.73	0.18	6*	3.69	0.69	0.19	12	2.95	1.29	0.44	20	3.43	1.34	0.39	10
R2	3.93	0.73	0.19	9	3.24	1.07	0.33	21	2.68	1.23	0.46	21	2.86	1.24	0.43	20
R3	4.25	0.75	0.18	1*	3.67	0.9	0.25	13	3.21	1.23	0.38	12	3.29	1.25	0.38	14
R4	4.14	0.73	0.18	4*	3.82	0.98	0.26	9	3.84	0.79	0.21	6	3.91	0.61	0.16	6
R5	4.16	0.71	0.17	3*	3.75	1.19	0.32	10	3.87	0.74	0.19	5	3.2	1.35	0.42	15
R6	3.36	1.35	0.40	19	3.33	1.14	0.34	20	3	1.21	0.40	18	4.11	0.76	0.18	3*
R7	3.11	1.37	0.44	20	3.35	1.19	0.36	19	3.68	0.78	0.21	9	4.09	0.7	0.17	4*
R8	3.68	0.71	0.19	15	3.67	1.17	0.32	13	3.63	0.71	0.20	11	3.03	1.45	0.48	17
R9	3.09	1.31	0.42	21	3.58	1.15	0.32	15	2.97	1.08	0.36	19	4.14	0.49	0.12	2*
R10	3.73	0.76	0.20	14	4.25	0.52	0.12	3*	3.74	0.72	0.19	8	3.51	1.15	0.33	9
R11	3.86	0.73	0.19	11	3.87	0.77	0.20	8	3.03	1.05	0.35	17	2.74	1.36	0.50	21
R12	3.75	0.81	0.22	13	4.07	0.66	0.16	6*	3.05	0.93	0.30	15	3.57	1.22	0.34	7
R13	3.93	0.76	0.19	9	4.38	0.65	0.15	1*	3.11	1.2	0.39	14	4.2	0.63	0.15	1*
R14	3.5	1.07	0.31	18	4.05	1.11	0.27	7*	3.97	0.68	0.17	4	3.94	0.91	0.23	5
R15	3.59	0.84	0.23	17	3.73	0.95	0.25	11	3.05	0.99	0.32	15	3.37	1.24	0.37	11
R16	3.84	0.71	0.18	12	4.11	0.71	0.17	5*	4.11	0.61	0.15	3*	3.54	1.31	0.37	8
R17	4.18	0.69	0.17	2*	3.47	0.79	0.23	18	4.18	0.61	0.15	2*	3.31	1.26	0.38	13
R18	4.09	0.8	0.20	5*	3.51	1.12	0.32	16	4.29	0.57	0.13	1*	3	1.46	0.49	18
R19	3.98	0.73	0.18	8	3.51	1.14	0.32	16	3.66	0.75	0.20	10	3.11	1.35	0.43	16
R20	3.66	0.71	0.19	16	4.18	0.72	0.17	4*	3.16	1.1	0.35	13	2.97	1.22	0.41	19
R21	4.05	0.71	0.18	7*	4.33	0.8	0.18	2*	3.79	0.7	0.18	7	3.34	1.26	0.38	12

Note: "" means that the level of stakeholders' concern of this risk is high (with the mean of above 4).*

SD and CV are the common measures of data dispersion. Narrow SD and CV indicate that data are stable and reliable and that respondents in the same group reach a consensus on the level of risk concern. The range of mean ± 1.64 SD is viewed as the consensus criterion for the items with a four-point Likert scale (Rogers and Lopez, 2002; West and Cannon, 1988). A wider range can be used for the consensus evaluation in this study with a five-point Likert scale. It is shown in Table 3.2 that all the SDs are below 1.46 and that the SDs of almost all the risks with high levels of stakeholders' concern (with the mean of above 4) in each group are below 0.80. Compared to SD, CV is a more standardized measure of statistics data dispersion and is calculated as SD divided by the mean. A CV below 0.5 is believed to indicate a reasonable and good internal agreement (English and Kernan, 1976; Zinn et al., 2001). All the coefficients of variation (CVs) listed in Table 3.2 are below 0.5. In particular, the CVs of almost all the risks with high levels of stakeholders' concern in each group are below 0.2.

The government is concerned with all risks, because none of the scores are less than 3.09. Among all risks, lack of awareness of energy-efficient retrofitting (R3), poor performance in cooperation (R17), and insufficient funds available (R5) are given the highest scores, followed by lack of government departments' coordination and support (R4), opportunistic renegotiation (R18), frequent change in demolition policies (R1) and difficulties in post-retrofit repair (R21) that also score more than 4.05. These risks are caused by homeowners' poor understanding and cooperation.

Similarly to the government, all risks are concerned by homeowners, and the scores range from 3.24 to 4.38. The scores of moral hazard (R13), difficulties in post-retrofit repair (R21), unqualified building materials (R10), inadequate maintenance (R20), poor safety management (R16), lack of construction skills (R12), and poor quality of old residential buildings themselves (R14) are more than 4 and are dominant among all risks. These risks are associated with project quality and safety.

Contractors have the most significant concern about opportunistic renegotiation (R18), poor performance in cooperation (R17), and poor safety management (R16). The three risks exist in the phase of site implementation and are associated with homeowners.

Designers express more concern about four risks of moral hazard (R13), lack of appropriate technical standards (R9), insufficient information regarding the buildings (R6), and uncertainty on the on-site conditions (R7) with scores of over 4. These risks are relevant to drawing a retrofitting plan and implementing the plan.

3.4.2 Comparison of risk concern among all stakeholder groups

Levene's test for equality of variances is first conducted, and the test results with a significance value (p-value) are shown in Table 3.3. According to the results, the assumption of homogeneity of variance is only valid for the risk of poor construction management (R15).

TABLE 3.3 Test of Homogeneity of Variances

	Levene Statistic	df1	df2	Sig.
R1	12.538	3	168	0.000
R2	5.269	3	168	0.002
R3	7.480	3	168	0.000
R4	3.569	3	168	0.015
R5	10.657	3	168	0.000
R6	4.948	3	168	0.003
R7	12.905	3	168	0.000
R8	11.322	3	168	0.000
R9	10.011	3	168	0.000
R10	12.195	3	168	0.000
R11	7.616	3	168	0.000
R12	9.997	3	168	0.000
R13	5.602	3	168	0.001
R14	5.255	3	168	0.002
R15	2.355	3	168	0.074
R16	15.567	3	168	0.000
R17	13.751	3	168	0.000
R18	11.888	3	168	0.000
R19	10.384	3	168	0.000
R20	4.364	3	168	0.005
R21	10.947	3	168	0.000

The results of one-way ANOVA can be used to directly compare the concern of all the stakeholder groups on R15, while the Welch test is applied in judging the significance of differences in the other 20 risks (shown as Table 3.4 and Table 3.5). Stakeholder groups hold different opinions on most of the risks, but there is no significant difference in the concern regarding three risks, namely lack of government departments' coordination and support (R4), lack of technical staff with specific expertise (R8) and poor quality of old residential buildings themselves (R14).

TABLE 3.4 ANOVA for R15

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	11.243	3	3.748	3.756	0.012
Within Groups	167.612	168	0.998		
Total	178.855	171			

TABLE 3.5 Robust tests of equality of means except for R15

	Statistica	df1	df2	Sig.
R1	8.318	3	80.672	0.000
R2	14.465	3	84.781	0.000
R3	10.332	3	83.995	0.000
R4	1.523	3	91.386	0.214
R5	5.340	3	87.177	0.002
R6	9.843	3	90.012	0.000
R7	7.740	3	91.931	0.000
R8	2.072	3	86.843	0.110
R9	17.738	3	88.409	0.000
R10	9.943	3	80.694	0.000
R11	12.231	3	82.962	0.000
R12	11.520	3	82.316	0.000
R13	12.847	3	85.769	0.000
R14	2.551	3	90.354	0.061
R16	2.910	3	85.437	0.039
R17	12.882	3	86.380	0.000
R18	12.344	3	86.729	0.000
R19	4.805	3	87.227	0.004
R20	14.911	3	82.535	0.000
R21	7.363	3	85.938	0.000

As a whole, lack of government departments' coordination and support (R4) and poor quality of old residential buildings themselves (R14) are given more concern by almost all the stakeholder groups, while lack of technical staff with specific expertise (R8) is ranked in the middle and lower tiers by all stakeholders. Every stakeholder group expresses expectations to obtain the support of the relevant government departments in order to seek an extremely favourable environment to work. Likewise, quality problems attributed to buildings themselves have severe negative impacts on retrofitting quality that is focused on all of groups. By contrast, designers' capacities are not paid too much attention.

3.4.3 Comparison of risk concern within different pairs of groups and the corresponding proactive measures

According to the results of the test of homogeneity of variances, Scheffe's test is adopted to make comparisons on R15 between any two stakeholder groups, while Games-Howell test is used to compare the other risks except R4, R8 and R14. The test results with mean difference and significance value (p-value) are shown in Table 3.6 (G = Government, H = Homeowners, C = Contractors, D = Designers). There is no particular stakeholder group with significant differences from all the others in terms of risk concern, but the differences between government and designers and between homeowners and contractors are the most significant among all the six pairs of comparisons.

Table 3.7 summarized the risks with great concern for each stakeholder group (based on Table 3.2) and also highlighted the stakeholder groups who have significantly less concern about each risk than the former group (based on Table 3.6) (G = Government, H = Homeowners, C = Contractors, D = Designers). It is also shown in Table 3.7 whether stakeholder groups with high levels of risk concern have taken measures for proactive risk management or not. Almost all the stakeholder groups tend to proactively mitigate risks they have more concern about. However, the majority of these proactive risk mitigation measures are considered limited and cannot mitigate these risks well. The details of proactive risk management are shown in Table APP.B.1 in Appendix to Chapter 3.

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TABLE 3.6 Mean differences between pairs of stakeholder groups

	G and H			G and C			G and D			H and C			H and D			C and D		
	MD	SE	Sig.	MD	SE	Sig.	MD	SE	Sig.	MD	SE	Sig.	MD	SE	Sig.	MD	SE	Sig.
R1	0.377	0.144	0.050	1.121*	0.237	0.000	0.640	0.251	0.065	0.744*	0.230	0.011	0.262	0.244	0.706	−0.481	0.308	0.407
R2	0.695*	0.181	0.001	1.248*	0.228	0.000	1.075*	0.237	0.000	0.552	0.247	0.123	0.379	0.255	0.449	−0.173	0.290	0.933
R3	0.577*	0.166	0.004	1.039*	0.230	0.000	0.964*	0.240	0.001	0.462	0.234	0.209	0.387	0.244	0.394	−0.075	0.291	0.994
R5	0.414	0.193	0.148	0.291	0.161	0.281	0.959*	0.252	0.002	−0.123	0.201	0.928	0.545	0.278	0.214	0.668	0.257	0.057
R6	0.036	0.255	0.999	0.364	0.282	0.573	−0.751*	0.240	0.014	0.327	0.249	0.557	−0.787*	0.200	0.001	−1.114*	0.234	0.000
R7	−0.232	0.261	0.811	−0.571	0.241	0.094	−0.972*	0.238	0.001	−0.339	0.204	0.35	−0.740*	0.200	0.002	−0.402	0.173	0.102
R9	−0.491	0.251	0.213	0.117	0.264	0.97	−1.052*	0.214	0.000	0.608	0.234	0.052	−0.561*	0.176	0.011	−1.169*	0.194	0.000
R10	−0.527*	0.134	0.001	−0.010	0.164	1.000	0.213	0.225	0.780	0.518*	0.137	0.002	0.740*	0.206	0.004	0.223	0.227	0.760
R11	−0.009	0.152	1.000	0.837*	0.203	0.001	1.121*	0.255	0.000	0.846*	0.200	0.000	1.130*	0.252	0.000	0.283	0.286	0.755
R12	−0.323	0.151	0.152	0.697*	0.194	0.003	0.179	0.240	0.878	1.020*	0.175	0.000	0.501	0.225	0.130	−0.519	0.255	0.187
R13	−0.450*	0.144	0.013	0.827*	0.226	0.003	−0.268	0.157	0.324	1.277*	0.214	0.000	0.182	0.138	0.557	−1.095*	0.223	0.000
R15	−0.136	0.202	0.928	0.538	0.221	0.120	0.219	0.226	0.815	0.675*	0.211	0.019	0.356	0.216	0.440	−0.319	0.234	0.604
R16	−0.268	0.144	0.252	−0.264	0.146	0.274	0.298	0.247	0.625	0.004	0.137	1.000	0.566	0.242	0.103	0.562	0.243	0.109
R17	0.709*	0.149	0.000	−0.002	0.144	1.000	0.868*	0.236	0.003	−0.711*	0.145	0.000	0.158	0.237	0.909	0.870*	0.234	0.003
R18	0.582*	0.193	0.017	−0.199	0.152	0.560	1.091*	0.274	0.001	−0.780*	0.177	0.000	0.509	0.289	0.301	1.289*	0.263	0.000
R19	0.468	0.189	0.070	0.319	0.164	0.215	0.863*	0.253	0.007	−0.149	0.195	0.871	0.395	0.274	0.480	0.544	0.258	0.163
R20	−0.523*	0.145	0.003	0.501	0.209	0.088	0.688*	0.233	0.024	1.024*	0.204	0.000	1.210*	0.229	0.000	0.186	0.274	0.904
R21	−0.282	0.152	0.254	0.256	0.157	0.367	0.703*	0.238	0.024	0.538*	0.157	0.005	0.984*	0.238	0.001	0.447	0.241	0.262

Note: "" means that the difference in the concern about this risk between two stakeholder groups is significant; G = Government, H = Homeowners, C = Contractors, D = Designers.*

TABLE 3.7 Comparisons of risk perception within different pairs of stakeholder groups

	Risks with high concern	G	H	C	D	Taking proactive measures for risk mitigation
G	R1: Frequent change in demolition policies			1.121*		Yes
	R3: Lack of awareness of energy efficiency retrofitting		0.577*	1.039*	0.964*	Yes
	R4: Lack of government departments' coordination and support					Yes but limited
	R5: Insufficient funds available				0.959*	Yes but limited
	R17: Poor performance in cooperation		0.709*		0.868*	Yes
	R18: Opportunistic renegotiation		0.582*		1.091*	Yes but limited
	R21: Difficulties in post-retrofit repair				0.703*	No
H	R10: Unqualified building materials	0.527*		0.518*	0.740*	Yes but limited
	R12: Lack of construction skills			1.020*		No
	R13: Moral hazard	0.450*		1.277*		Yes but limited
	R14: Poor quality of old residential buildings themselves					Yes but limited
	R16: Poor safety management					Yes
	R20: Inadequate maintenance	0.523*		1.024*	1.210*	Yes but limited
	R21: Difficulties in post-retrofit repair			0.538*	0.984*	No
C	R16: Poor safety management					Yes
	R17: Poor performance in cooperation		0.711*		0.870*	Yes but limited
	R18: Opportunistic renegotiation		0.780*		1.289*	Yes but limited
D	R6: Insufficient information regarding the buildings	0.751*	0.787*	1.114*		Yes
	R7: Uncertainty on the on-site conditions	0.972*	0.740*			Yes but limited
	R9: Lack of appropriate technical standards	1.052*	0.561*	1.169*		Yes but limited
	R13: Moral hazard			1.095*		Yes but limited

Note: "" means that the difference in the concern about this risk between two stakeholder groups is significant; Note: G = Government, H = Homeowners, C = Contractors, D = Designers.*

3.5 Discussion

3.5.1 Tendency of risk perception

According to risks with high concern shown in Table 3.7, it is easier for the government and industry stakeholders to perceive the risks associated with their own responsibilities due to their own professional roles. Correspondingly, these risks are also the focus of their proactive risk management. As the leader and sponsor of retrofit projects, the government is mainly responsible for the organization and decision making of projects. For this reason, the government tends to take a holistic view of these risks and pays more attention to the overall enforceability of retrofit projects instead of the details concerning design and construction. As for the matters relating to design and construction, the government is more willing to depend on those professionals who keep good cooperative relationships with the government. By contrast, designers and contractors also have more concern about the factors affecting the fulfilment of their duties, like the lack of objective information or uncooperative partners. This is in line with the views of Gambatese et al. (2008), who stated that that stakeholders' perception is affected by their roles and responsibilities through the project process. There is an intragroup consistency and intergroup inconsistency of risk perception due to the differences in interests and roles of stakeholder groups (Zhao et al., 2016).

Unlike the above three stakeholder groups, homeowners, as the owners and end-users of projects, attach more importance to the retrofit effects, which is considered the key to safeguard their own interests (see Table 3.7). They focus on the improvement of building quality and appearance and thus have more concern about the risks associated with on-site construction, including whether materials and contractors are qualified, whether contractors can conduct themselves lawfully, and whether their safety can be ensured. This is different from the traditional interests of homeowners. Homeowners in the international context generally have more concern about the cost-benefit analysis to make sure that their costs can be offset by retrofit benefits (including economic benefits and non-economic benefits) due to their roles as investors (Gamtessa, 2013; Stieß and Dunkelberg, 2013; Wilson et al., 2015). By contrast, cost-recovering is not the focus of homeowners in China since they do not need to bear the costs of retrofitting. In their opinion, the decrease in costs cannot contribute to the increase in their interests, and they attach more importance to the improvement of living quality.

3.5.2 Barriers to risk perception

It can be reflected in Table 3.2 that industry stakeholders tend to have confidence in their own professional ability, which makes it possible for the relevant risks to be ignored subjectively by these stakeholders. As the professional provider of the construction service, designers and contractors rarely question their abilities to deliver services but always worry about some external risks like the lack of objective information or uncooperative partners. This is concerned with their familiarity with design and construction work. The current energy efficiency technologies applied to the residential energy retrofit in China are relatively traditional, and there is no significant difference in the design and construction of energy-efficient measures between new-build projects and retrofit projects. This also convinces them that their professional expertise is enough to cope with the tasks in energy retrofit projects. Indeed, familiarity with a task can result in a decrease in risk perception (Zimolong and Elke, 2006). People's understanding of their actions lead to their optimistic views of the relevant risks, and these risks are thus considered to be under control (Van der Pligt, 1996). Such low perception can, in turn, weaken the incentives for the continuous improvement of their professional abilities.

In the comparisons between governments and both homeowners and designers in Table 3.7, governments are generally optimistic about designers' competence of making up for the shortage of technical standards (R9) and homeowners' ability of post-retrofit maintenance (R20), but such optimism is not recognized by designers and homeowners. The only technical specification for energy retrofit of residential buildings in the HSCW zone was issued in 2012 but is very difficult to be enforced in practice. The local government is more inclined to assign and complete retrofit tasks as soon as possible rather than spending much time improving the technical specification. In the opinions of the local government, retrofit schemes can be entirely dependent on designers' professional knowledge, even if there is a lack of technical guidance for retrofit design. This was viewed by Wildavsky and Dake (1990) as the individualist bias in culture theory, and it is believed that the severity of technical risks can be controlled and compensated for by technical institutions. However, designers actually complain that they do not know how to design the retrofitting schemes for old residential buildings due to the lack of specifications, so that they can only apply some necessary energy-efficient measures of new-built projects to retrofit projects, including the installation of insulation layers on roofs and exterior walls as well as the installation of windows with double glazing. It is also these limited and relatively simple retrofit measures that lead to the optimism of the local government about homeowners' performance in the operation and maintenance after retrofitting. Instead, homeowners themselves are not convinced due to the lack of guidance and assistance.

3.5.3 Conflicts of risk perception

Based on the comparisons between homeowners and contractors in Table 3.7, it seems hard for them to perceive the risks posed by their own actions, especially related to opportunism. Both homeowners and contractors have opportunities during the on-site construction to adopt opportunistic behaviours. In homeowners' opinions, contractors' breaching of contracts by cutting corners has a direct negative impacts on living comfort after retrofitting, but homeowners' poor cooperation and opportunistic requirements, causing project delay and cost increase, are regarded by themselves as a reasonable approach to perfecting the retrofit and building a better living environment. Xenidis and Angelides (2005) and Loosemore et al. (2012) viewed this as a bias resulting from contradictory interests. Similarly, for contractors, the execution of construction work requires cooperation from the homeowners, including the removal of obstacles in the pubic area, the placement of building materials, the negotiation of home-entry construction, etc. Meanwhile, faced with homeowners' unexpected demands like opportunistic compensation and unplanned retrofit requirements, contractors need to spend more time and costs on the negotiation with homeowners and the adjustment of construction schemes. However, contractors believe that they take the government projects more seriously and perform the contract strictly, and thus tend to neglect the risk arising from their opportunistic behaviours. Indeed, few people can acknowledge the relationships between their actions and the potential risks (Weinstein, 1984).

In terms of risks given high levels of concern by homeowners, it can be seen from the comparisons between homeowners and others in Table 3.7 that there are great differences in the perception of some construction-related risks between homeowners and practitioners. Homeowners cast doubt on contractors' abilities and material quality as well as even the legalization of their actions. Excessive concern leads to their suspicion of whether these residential buildings can be renovated as they expected or not, which, in turn, affects their cooperation with contractors to some extent. As with the views of Ward and Chapman (2008), stakeholders' approaches to risk mitigation arising from their perception of risks are likely to only focus on their benefits and thus to be detrimental to others. Influenced by risk perception, homeowners are more inclined to strengthen self-protection by making more requests for retrofitting. By contrast, the government does not view these risks as concerns, as believed by homeowners. In general, contractors are selected by the government through bidding, and such selection is also built on trust. Indeed, the differences in risk perception are related to the lack of confidence in people producing risks (Poortinga and Pidgeon, 2003). Moreover, project staff who feel untrusted are more likely to have moral hazard behaviours (Atkinson et al., 2006), which also means that contractors' opportunism originates from homeowners' mistrust to some extent.

3.5.4 Insights from risk perception and TCs considerations

Decrease in homeowners' risk perception plays an important role in promoting homeowners' participation and cooperation, which also contributes to the mitigation of homeowner-associated risks. Information is essential to the adjustment of risk perception. Consumers' risk perception is dependent on product-related information collected from various sources (Liu et al., 1998) and risk perception is, in turn, also a direct predictor of information seeking (Huurne and Gutteling, 2008). Information search is one of the primary sources of TCs that are viewed to affect make–buy decisions (Walker and Weber, 1984). From a TCs perspective, insufficient effective information leads homeowners to bear higher costs of information search, which is not only detrimental to the shaping of low levels of risk perception but also to their rational decision making on their involvement in energy retrofitting projects. In the Chinese context, the development of residential energy retrofit relies mostly on the government's propaganda and sponsorship. The local government is the main decision maker about the selection of projects, designers, and contractors as well as the scope of retrofit items, although homeowners' approval is still the premise of project initiation and the execution of design schemes. Few homeowners have access to sufficient project information in practice. In particular, the relationships between homeowners and other project parties are new and more temporary, which leads homeowners to have no prior knowledge of others' experience and reliability. To lower homeowners' concern about project risks, other parties should provide initiatively more positive and understandable information about material quality, expertise of construction staff, safety guarantee, and post-retrofit maintenance. Moreover, the government and contractors should create a more transparent environment for the follow-up information on retrofit construction in order to enable homeowners to realize that their home is being improved with the help of other project parties.

It is essential for other stakeholder groups to enhance their risk perception and to improve the feasibility and effectiveness of proactive risk management measures. In consideration of the tendency of stakeholders' risk perception towards their own responsibilities, there is a need for all of stakeholder groups to share the risks posed by them in order to trigger their awareness of proactively mitigating these risks. For example, industry stakeholders are required to enhance the technical knowledge to ensure the quality of their service; the government should assist in the development of technical guidance of energy retrofit and the establishment of systematic post-retrofit maintenance. Indeed, risk allocation is viewed as an approach to responsibility sharing and has high impacts on stakeholders' behavioural motivations (Ward and Chapman, 2008). However, risk allocation requires the investment of resources, which is also likely to limit stakeholders' actions for risk mitigation.

Economic condition is considered as one of the leading causes of the weak relationships between risk perception and stakeholders' actions (Wachinger et al., 2013). Both uncertainties in the environment of proactive risk management and asset specificity concerning stakeholders' own abilities and resources give rise to higher TCs in the risk management transaction, which further restrict their behaviours in proactive risk management. There is no need for each stakeholder group to be involved in proactive management of all risks that are relevant to them. For instance, although homeowners and contractors need to be jointly responsible for on-site construction safety, it seems that contractors, owning experience and professional knowledge, can undertake more extra work with lower searching costs and monitoring costs to prevent safety issues. TCs incurred by proactive risk mitigation (e.g., searching costs, learning costs, negotiation costs, monitoring costs, etc.) should be considered in the risk allocation of energy retrofit projects in order to make sure that risk mitigation behaviours of risk takers can be carried out successfully and effectively.

3.6 Conclusion

Energy retrofits of residential buildings in China are exposed to many risks due to the involvement of various stakeholders. Proactive risk management is a more functional approach to project success and can help economize on TCs by controlling uncertainty to smoothen the whole process of energy retrofit projects. Stakeholders' proactive actions for risk mitigation are based on their perception of these risks. Perceived risks are different from real risks, and contradictions of risk perception among different stakeholder groups can also result in the conflicts of risk mitigation practices. In order to motivate stakeholders' proactive management for real risks, it is essential to have a good understanding of stakeholders' present risk perception. This study analysed and compared the perception of four main stakeholder groups of 21 risks (identified from a literature review and interviews) in residential energy retrofit projects in the form of risk concern. The proactive measures of different stakeholder groups for risk mitigation were also explored through interviews to validate the relationships between high levels of risk perception and proactive risk management.

Responsibilities and interests are the focus of stakeholders' risk perception, and high levels of risk perception can drive people to take proactive measures for risk management. The risk perception of government and industry stakeholders generally originate from their sense of duty as the project organizer and service providers, while homeowners tend to view their interests as a base of risk perception. Correspondingly, all the stakeholder groups are active in proactive mitigation for these risks. However, influenced by individuals' knowledge and external environment factors, the effectiveness of some proactive measures is not enough. Homeowners cannot do much about the risks relevant to professional knowledge (e.g., skills and work normativity of construction staff, quality of materials and buildings, and building maintenance). Designers have limited roles in the operational normativity of construction staff and the making up of the deficiency of some external information. By contrast, in terms of the risks concerning the coordination and support from other groups, proactive measures of the government are limited. Likewise, the contractors do not have sufficiently effective measures to proactively mitigate the risks arising from homeowners' cooperation.

It is essential for proactive risk management to enhance the risk perception of risk-source-related stakeholder groups in consideration of their more effective proactive measures compared to the affected groups. Stakeholders related to risk sources should share the risk, and their increased responsibilities can motivate them to enhance their awareness of proactive risk management. The government and contractors need to take more responsibilities for construction quality and maintenance. The government should set more explicit standards for the selection of retrofitting projects, construction materials, and contractors. Meanwhile, it is necessary to clarify contractors' responsibilities in respect to the procurement of materials, personnel abilities, service normativity, and post-retrofitting quality warranty. Furthermore, the government also needs to shoulder some responsibilities for design work, including not only developing more specific design standards but also assisting designers to probe deeper into buildings and the surroundings. TCs have an important role in both the enhancement of risk perception and responsibility sharing. Risk allocation with TCs considerations can make responsibility sharing more reasonable and effective and further drive the achievement of stakeholders' proactive risk management.

Homeowners' proactive measures also need to be encouraged, which can be achieved through changes (including both enhancement and reduction) in their risk perception. The key to managing the homeowner-associated risks lies with the enhancement of their self-awareness of active cooperation. Responsibility sharing (e.g., encouraging homeowners to bear some of retrofitting costs) contributes to reducing the barriers from homeowners during the construction period. Meanwhile, the decrease in homeowners' perception of risks caused by other stakeholder groups is also necessary to motivate homeowners' cooperative awareness. Sufficient and effective information should be provided to reduce homeowners' risk perception, which is also an approach to lowering TCs borne by homeowners and to further improving their initiative of participation and cooperation.

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4 How Information Stimulates Homeowners' Cooperation

in Residential Building Energy Retrofits in China

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ABSTRACT

The process of residential energy retrofitting needs to be advanced, especially in the hot summer and cold winter (HSCW) zone of China. Good cooperation from homeowners is the key to the smooth project implementation. Some studies have identified four categories of information as important factors affecting homeowners' decision-making in retrofitting. Such information can improve homeowners' cooperation to some extent. This study investigates the nature of this influence mechanism of retrofitting information, so as to stimulate homeowners' cooperation. The authors, first, explain how the direct relationship between information and homeowners' level of cooperation was validated. Second, under the mediation role of risk perception, we verify the indirect influence of such information. Third, we analyse the variation in the strength of the relationships between information and homeowners' cooperation under the influence of source credibility. It is concluded that providing information on retrofitting benefits and service is more effective for improving homeowners' cooperation. The integrity of building quality information and the understandability, to the homeowners, of technology information need to be considered. Priority should be given to the sources of expert knowledge and

published resources, because they are perceived by homeowners to be relatively credible. Policy suggestions are proposed based on the results.

KEYWORDS Building energy retrofitting; Homeowners' cooperation; Retrofitting information; risk perception; Information source credibility

4.1 Introduction

Worldwide, the retrofitting of older residential buildings to save energy has been recognized as an important approach to energy conservation and the mitigation of climate change. The GlobalABC Global Roadmap has viewed building retrofitting as one of the key priorities for mitigating the buildings' influence on energy consumption and climate (UNEP, 2016). From 2018, all EU member states were required by the updated Energy Performance of Buildings Directive (EPBD) to carry out long-term retrofitting strategies for the achievement of a highly efficient and fully decarbonized building stock by 2050 (IEA, 2018).

China is no exception and has highlighted residential buildings as a key potential area for energy-savings through energy-efficiency improvement since 2006 (GOSC, 2011; NDRC, 2006). In 2017, residential building retrofitting in both the northern region and the hot summer and cold winter (HSCW) zone also continued to be considered in the latest national plan as one of the main tasks for energy conservation and emissions reduction (MOHURD, 2017). However, there is an unbalanced development of energy retrofits existing between these two regions in China. For example, compared with the retrofitting achievements during the "12th Five-year Plan" period of 990 million m^2 (of floor area) in the northern region, the retrofitting projects that were completed in the HSCW zone, during the same period, were very limited, such that the floor area completed was only 70.9 million m^2. Indeed, more energy consumption is expected for heating in winter and cooling in summer to adjust to people's rising expectations in thermal comfort, especially in the HSCW zone where there is no regional heating (Baldwin et al., 2018). It is, therefore, necessary to speed up the process of energy retrofitting of residential buildings in the HSCW zone of China.

Both the participation of homeowners and also their cooperation are vital to the success of energy retrofits. The multi-owner apartment building is the main form of urban residential buildings in China, and so it is also the main object of

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energy retrofitting. For buildings with individual private-property rights, each homeowner has the ownership of their own apartment. They can lawfully possess, utilize, profit from and sell house property. All homeowners share ownership of the common parts of a building, but the land is owned by the state. The successful retrofit of these ‘multi-dwelling’ buildings is necessarily preceded by residents’ collective participation and cooperation (Cirman et al., 2011). In China, the level of cooperation of homeowners can be reflected by their acceptance of retrofitting plans, their assistance in retrofitting construction, and their facilitation of the maintenance of post-retrofitting buildings, all of which also determines whether energy retrofitting projects can be implemented smoothly.

Energy retrofits in China are generally carried out based on the units of residential quarters, and several apartment buildings make up one residential quarter. The retrofitting priority is given to old residential buildings with poor thermal performance of the building envelope, but with good seismic and structural safety performance (MOHURD, 2013). Laws, regulations and industry standards related to property management were gradually issued after 2003 in China. Property service enterprises are responsible for the maintenance, repair and remediation of management items, such as buildings and equipment, municipal public facilities, greening, sanitation, transportation, public security, and environment in a residential quarter. Most of the older residential quarters built before 2003 rarely introduced professional property managers to maintain the buildings before retrofitting, and so they are heavily dependent on the self-management by the co-owners. The central government has not issued any official documents to specify the share of homeowners’ contributions to energy retrofitting. Although the Ministry of Housing and Urban-Rural Development of China in 2008 suggested a contribution of 15% to 20%, homeowners contributed less than this percentage (or even only 5% to 10%), for the retrofitting projects co-funded by the government and homeowners in practice. In particular, in the HSCW zone, where residential energy retrofitting has not been implemented on a large scale, government finance is still the main, or even the only, funding source. The common retrofitting items in the HSCW zone include lighting, doors, windows, roofs, and external walls.

The cooperation of homeowners is involved in the whole process of energy retrofitting projects. In owner-occupied homes in the US and many European countries, homeowners adopt the role of investors and so their decisions to retrofit are the theoretical premises of building retrofits (Wilson et al., 2015). Their cooperation with contractors in conducting construction work is an important part of homeowners’ participation (Suschek-Berger and Ornetzeder, 2010). Similarly, in China, even if homeowners are mostly viewed as beneficiaries, instead of investors, they still need to play an important role in retrofit planning, retrofit implementation and the use of technologies (Liu et al., 2015). Building retrofits rely on a certain degree of participant involvement for the successful achievement of a common goal (Liu et al., 2015). At present, homeowners play a limited role of retrofitting decision-making in China. Their decisions involve: a) the approval of renovating their residential quarters that have been included by the local government in the retrofitting plan; b) their selection of retrofitting technology within the prescribed limits by the local government; and c) the approval of the design scheme that has been made. In the case that homeowners do not bear the expenses of retrofitting, or they only pay a minimal fee, homeowners' requirements are limited within the scope of government's affordability, and of works being in the interests of most homeowners. This scope is based on the financial budget and technical feasibility and is defined by the local government. Homeowners' cooperation also needs to be valued at both the stages of on-site construction and the later usage of retrofit projects, involving: a) cooperating with the contractors to implement the retrofitting schemes that are selected and approved by homeowners themselves; as well as b) at the stage of cooperating with the community or property service company to maintain the residential quarters after retrofitting. However, the divergence of interests among homeowners often leads to the difficulties in reaching a consensus on decision-making, and so affects their intentions to actively cooperate, which is also one of the barriers to the promotion of energy retrofitting in China (Jia et al., 2018a; Jia et al., 2018b; Liang et al., 2016). Uncooperative members, especially at the stage of construction, result in construction delays and budget overruns, and delays in retrofit projects might lead to more disturbance to occupants and existing building operations (Hwang et al., 2015). Moreover, homeowners' cooperation can actually be regarded as family decision-making in China, especially for elderly homeowners. Adults generally provide informal home care and financial support for their aging parents in China (Hu et al., 2020; Ouyang et al., 2018). With the increase in young people's income, the role of the elderly in the family has been significantly weakened, and their consumption decisions mainly rely on the opinions of their adult children (PWC, 2018). Similarly, education is an important factor affecting the power of family decision-making. With the improvement of education quality and higher education expansion, Chinese young adults have access to more educational resources, making their education levels generally higher than that of their parents. Resource theory argues the family member of decision-making power varies with his or her resources (e.g. education) (Blood and Wolfe, 1978). The level of education can determine who is responsible for family decision-making to some extent (Bertocchi et al., 2014; Doss, 2013; Li et al., 2021).

One other factor of importance to the level of cooperation of homeowners is their understanding of the whole need and process of retrofitting. This can be a significant information barrier, and is one of the most critical factors hindering homeowners' engagement in energy retrofitting, due to the complexity of the building retrofitting process (Novikova et al., 2011b). Imperfect information is suspected to be the most important failure in the energy efficiency market (Huntington et al., 1994). If homeowners do not understand retrofits, it is difficult to increase their enthusiasm for building energy retrofitting (Novikova et al., 2011a). Meeting homeowners' information needs for their engagement in the retrofitting process can enhance their acceptance of building energy efficiency (Sabet and Easterbrook, 2016). Lack of information is also one of the obstacles of energy retrofitting in China (Liu et al., 2020a). This "Information asymmetry" leads to the scarcity of public awareness of building energy efficiency (Li and Shui, 2015; Zhang and Wang, 2013). In particular, there is a lack of platforms and activities for sharing the retrofitting information, which also results in low public awareness of energy retrofitting (Jia et al., 2018a; Jia et al., 2018b). Recently, pilot projects and public participation activities have been adopted in China, to share the retrofitting information with the public, and to promote building energy retrofitting (Liu et al., 2020a). The Chinese central government has carried out many pilot retrofitting projects (e.g., Sino-German Technical Cooperation (2005-2011)). The public can search for the information on these pilot projects in the network platform to know more about energy retrofitting. Moreover, the community can popularize the knowledge about retrofitting, including through expert consultation and advice in the 'National Energy Conservation Publicity Week' and 'National Low Carbon Day' Activities. However, at present, the central government still seems to ignore the importance of retrofitting information dissemination and energy consumption disclosure, so that the public generally have insufficient knowledge about energy retrofitting, which, in turn, also limits their retrofitting enthusiasm (Liu et al., 2020b). It is necessary for the promotion of energy retrofitting in China to improve the information provided for homeowners to motivate them to cooperate. A deep understanding of the influence mechanism of information on homeowners' cooperative behaviors is thus required to ensure the effectiveness of the provided information.

The information affecting homeowners' enthusiasm for participation and cooperation has been analysed by some researchers (Jakob, 2007; Palmer et al., 2015; Syal et al., 2014; Wilson et al., 2014; Wilson et al., 2015), but is mostly related to energy audit, retrofitting costs and benefits and used for investment decision-making. Besides, the existing studies tend to highlight homeowners' participation in the selection of retrofitting technology in order to improve the effectiveness of retrofitting after the completion of the project (Li et al., 2017; Liu et al., 2015; Lo, 2015). Few researchers investigate homeowners' cooperation from the perspective of the whole-process of participation.

To fill this gap, this study investigates how to provide effective information to motivate homeowners towards participation and cooperation in the whole process of energy retrofitting projects in the HSCW zone of China. It achieves this by analysing the influence mechanism of building retrofitting information. Such information effects also consider the roles of risk perception and information source credibility. In China, homeowners tend to have perceptions of high retrofitting risks, especially those at the stages of on-site construction and usage. Indeed, these risks are perceived as being higher by homeowners than perceptions from other stakeholder groups (e.g., the government, designers, and contractors) (Jia et al., 2020). This so-called *amplification of risk perception* is concerned with information transfer and the public's responses to information (Kasperson et al., 1988). Perceptions of high-risks can lead to an increase in the possibility of risk-averse behaviours (Chionis and Karanikas, 2018). Thus, people's participation in actions might be suppressed by their high-risk perception (Bindl and Parker, 2011). In addition to information quantity, information quality is also an important feature of information sharing (Thomas et al., 2009). Information source credibility is a significant factor to measure information quality (Khosrowpour, 2014). As mentioned earlier, homeowners in China can acquire retrofitting information from several sources (e.g., network platforms and experts). In a similar way, homeowners' perceived credibility of these sources acts on information effects, and also needs to be considered in analysing the information affecting homeowners' cooperation.

This study is organized as follows. First, the hypotheses are set up based on a review of existing theory in the literature to address the relationships among the four key variables: 1) Building retrofitting information; 2) Homeowners' cooperation; 3) Risk perception; and 4) Information source credibility. Second, the samples and measures employed in this study are described. Then, the empirical research results and discussions, based on a questionnaire survey, are also reported to examine the hypotheses. Finally, this study presents the findings and proposes some policy suggestions for future information provision.

4.2 Theory and hypotheses

4.2.1 Four areas of building retrofitting information and homeowners' cooperation

Given the background explained above, the homeowner's decision-making, i.e., the awareness of the need for retrofitting, the choice of retrofitting technology, the implementation of retrofitting measures, and the confirmation of retrofitting effect, runs through the whole process of energy retrofitting (Pettifor et al., 2015; Wilson et al., 2018). Access to relevant information is necessary for the decision-making of retrofitting activities (Stieß and Dunkelberg, 2013). For instance, homeowners' recognition of energy-retrofitting investment is based on the information on productivity (Bardhan et al., 2014); information is also required by homeowners to make optimal choices of retrofitting measures (Palmer et al., 2015). The retrofitting information that is provided for homeowners during the energy retrofitting has been summarized in Table 4.1.

This retrofitting information can be divided into four categories, including:

- **Building Information (BI)** representing the basic information before retrofitting;
- **Retrofitting Benefits (RB)** reflecting the advantages of energy retrofitting;
- **Retrofitting Technology (RT)** involving the methods of technology installation, usage and maintenance; and
- **Retrofitting Service (RS)** referring to the information on retrofitting service during the construction.

TABLE 4.1 Information on energy retrofitting of residential buildings

Information category	Information indicators	Reference
Building information (BI)	BI1:building structure	(Stieß and Dunkelberg, 2013)
	BI2:building physical conditions	(de Wilde and Spaargaren, 2019; Palmer et al., 2013; Wilson et al., 2014)
	BI3:energy use conditions	(de Wilde and Spaargaren, 2019; Sabet and Easterbrook, 2016; Wilson et al., 2014)
	BI4:energy losses	(Palmer et al., 2013; Syal et al., 2014)
Retrofitting benefits (RB)	RB1:preferential policies (e.g., subsidies/ government bearing retrofitting costs, and tax benefits)	(de Wilde and Spaargaren, 2019)
	RB2:energy savings	(de Wilde and Spaargaren, 2019; Palmer et al., 2013; Syal et al., 2014; Wilson et al., 2014; Wilson et al., 2015)
	RB3:financial savings	(de Wilde and Spaargaren, 2019; Sabet and Easterbrook, 2016; Syal et al., 2014; Wilson et al., 2015)
	RB4:effects on health and comfort	(de Wilde and Spaargaren, 2019; Sabet and Easterbrook, 2016; Wilson et al., 2014; Wilson et al., 2015)
Retrofitting technology (RT)	RT1:technology characteristics	(de Wilde and Spaargaren, 2019; Michelsen and Madlener, 2016; Syal et al., 2014)
	RT2:technology installation methods	(Stieß and Dunkelberg, 2013)
	RT3:usage of installed equipment	(Stieß and Dunkelberg, 2013)
	RT4:equipment maintenance	(Owen and Mitchell, 2015)
Retrofitting service (RS)	RS1:material quality	(de Wilde and Spaargaren, 2019; Sabet and Easterbrook, 2016; Syal et al., 2014)
	RS2:contractors' competence	(de Wilde and Spaargaren, 2019; Neuhoff et al., 2011; Syal et al., 2014; Wilson et al., 2014; Wilson et al., 2015)
	RS3:installation schedule	(Owen and Mitchell, 2015)
	RS4:construction tracking	(de Wilde and Spaargaren, 2019)
	RS5:construction service quality	(de Wilde and Spaargaren, 2019; Novikova et al., 2011b; Wilson et al., 2014)

The poor information available to homeowners is the key impediment to the energy retrofitting of residential buildings (Syal et al., 2014). Imperfect information about energy use, technology, and energy savings severely hampers the implementation of housing energy retrofitting (Hrovatin and Zorić, 2018). Homeowners' demand for energy-efficient upgrades is restricted by information imperfections (Bardhan et al., 2014). Golove and Eto (1996) viewed a lack of information on retrofit technology as the main reason for the failure of the energy efficiency market. Moreover, the increased information search costs of homeowners are induced by information asymmetry. The high costs to acquire relevant information limit homeowners' participation in improving building energy efficiency (Bardhan et al., 2014). Lack of targeted information and the induced transaction costs (e.g., search costs and monitoring costs) constitute critical barriers to the development of the energy efficiency market (Howarth and Andersson, 1993). Indeed, successful retrofitting is closely linked to those homeowners who can acquire more information from external sources (Risholt and Berker, 2013). In addition, the provision of effective information is an approach to not only reducing search costs (Ha, 2002), but also achieving pro-environmental behaviours (Catney et al., 2013).

The authors assert that information on building information, retrofitting benefits, and retrofitting technology is relatively neutral, while details on retrofitting services can be provided from both positive and negative perspectives. Neutral and positive information contributes to stimulating the consumption of environmentally-preferable products, and particularly positive information can guide consumers towards these products (Leire and Thidell, 2005). Compared to positive information, negative information is less likely to be communicated to help persuade and impact decisions about retrofitting (Siegrist and Cvetkovich, 2001). Consumers' decision-making is probably influenced partially by positive information, but they are unlikely to select the products with negative information (Grankvist et al., 2004). Thus, this study focuses only on positive information in terms of a retrofitting service. The first hypothesis is proposed as follows.

H1: Information has a positive influence on the level of homeowners' cooperation, such that increased information can improve homeowners' cooperation in energy retrofitting projects.

4.2.2 Risk perception as a mediator of the relationship between information and homeowners' cooperation

Risk perception is a kind of subjective assessment of risks by individuals (Pidgeon, 1998). The presentation of the relevant information is one of the factors causing individuals' differences in risk perception (Van der Pligt, 1996). Information is necessary for people to assess the risks, and people's exposure to information can shape their risk perception (Lindell and Perry, 2012). In fact, high levels of people's concern about risks can be considered to result from inadequate provision of information (Williams and Noyes, 2007). The information in the risky situation is more important to new consumers than to existing customers, and the results of information search contribute to the decrease in their overall risk perception (Ha, 2002). In particular, positive information on a specific object is likely to be conducive to a decrease in perceived risks about this object (Nedungadi et al., 2001).

People tend to respond and react subjectively to risks perceived, and their risk perception affects their behaviours and actions (Bauer, 1960). Risks in the building context are characterized by uncertainty (including uncertain events and uncertain impacts) (Chia, 2006). Uncertainty avoidance is a key principle of people's behaviours (Ketokivi and Mahoney, 2016). People usually take actions to avoid risks that are perceived by them to be serious (Mañez et al., 2016). As a result of risk aversion, high levels of risk perception can limit people's involvement in energy retrofitting. Measures that reduce homeowners' perception of risks are thus considered to contribute to the improvement of homeowners' participation and cooperation (Jia et al., 2020).

The existing studies in other fields have identified the relationships of the three factors of information, risk perception, and people's involvement. Williams and Noyes (2007) pointed out that risk perception is dependent on information sufficiency and is also an inherent factor influencing people's decision-making. From another context, Seabra et al. (2014) thought that information about terrorism has direct impacts on tourists' risk perception and affects their involvement in trip planning. Selma et al. (2014) found out that risk perception is an important influential variable for public acceptance of carbon capture and storage and is also affected by information to some extent. Therefore, this study presents the second hypothesis as follows.

H2: Information has a positive influence on the level of homeowners' cooperation through risk perception, such that increased information lowers risk perception and decreased risk perception further improves homeowners' cooperation.

4.2.3 Information source credibility as a moderator of the strength of the relationship between information and homeowners' cooperation

The intention of information receivers to use information is affected by their perceived credibility of information sources (Bannister, 1986). Information source credibility refers to the judgments of information receivers on the believability of information sources (Pornpitakpan, 2004). It determines how people view the information acquired from these sources as being believable (Baggett et al., 2006). Source expertise is an important element of source credibility and refers to the perceived competence of information providers (Pallavicini et al., 2017). When the information sources are perceived to be competent and trustworthy, the information is less challenged or doubted (McNie, 2007). Those deferring to information sources

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generally pay less attention to information content, and scrutinize the content only when the source is viewed as lacking in expertise (Gass, 2015). The credibility of information sources has an influence on the way people process information (Petty and Cacioppo, 1996), and highly credible sources are likely to boost the degree to which the information is processed (Trumbo and McComas, 2003). When source credibility is perceived to be high, information receivers are more likely to change their opinions in the direction guided by the information (Hovland and Weiss, 1951). Syal et al. (2014) divided the retrofitting information sources into two categories based on earlier work by the researchers: published information and expert knowledge. In the Chinese context, homeowners have opportunities to access experts for consultation and are also provided with professional retrofitting knowledge through the National Energy Conservation Publicity Week and National Low Carbon Day Activities. Meanwhile, they can, not only seek the professionals from the local pilot retrofitting projects for more information, but also, acquire the information about pilot projects on the public network platforms. Some professional websites about building energy efficiency also provide the information relevant to energy retrofitting. Besides, Hrovatin and Zorić (2018) thought that the informal information sources (e.g., personal contacts and social media) are also important in energy retrofitting projects. Likewise, homeowners in China can also collect the relevant information from their family, friends and neighbours in their own social network.

Pornpitakpan (2004) reviewed the studies on source credibility, and pointed out that information sources with high credibility were more persuasive than ones with low credibility, in terms of changing perceptions and attitudes as well as gaining behavioural compliance. Credibility and trustworthiness of information sources are identified by Petty et al. (1994) as the determinants of whether people accept information or not. Trust is one of the credibility dimensions and is commonly considered interchangeable with credibility (Jungermann et al., 1996). By encouraging people to accept information, trust increases the role of information in risk perception (Langford, 2002). Trust is an important determinant of public risk perception, and the success of risk communication is dependent on the trust in the people providing information (Smith and Brooks, 2013). The lack of consensus on risk perception is also concerned with a lack of trust in information sources (Poortinga and Pidgeon, 2003). Similarly, homeowners' distrust in information sources also limits the trustworthiness and effectiveness of information in energy retrofitting (Gram-Hanssen et al., 2007). Homeowners' involvement and cooperation are reliant on the acquirement of trusted information (Sabet and Easterbrook, 2016). Distrust in information about what retrofits are, why they are beneficial, and how to implement them is viewed as one of the main reasons for less support for energy retrofitting (Syal et al., 2014). Therefore, this study proposed the third hypothesis that is defined as H3. The strength of information's role moderated by source credibility in H3 includes the strength of information's direct and indirect effects as mentioned in H1 and H2, and the following H3a and H3b describe the moderation roles of source credibility in these two effects of information, respectively.

H3: Information source credibility moderates the strength of the influence of information on the level of homeowners' cooperation, such that information has a stronger positive effect on homeowners' cooperation when source credibility is perceived to be high.

H3a: High source credibility strengthens the positive direct effect of information on the level of homeowners' cooperation, such that increased information is more able to improve homeowners' cooperation in the case of high source credibility.

H3b: High source credibility amplifies the positive indirect effect of information on the level of homeowners' cooperation, such that increased information is more able to reduce risk perception in the case of high source credibility and further to enhance homeowners' cooperation.

Figure 4.1 integrates the above hypotheses to show the conceptual relationships among information, source credibility, risk perception, and homeowners' cooperation.

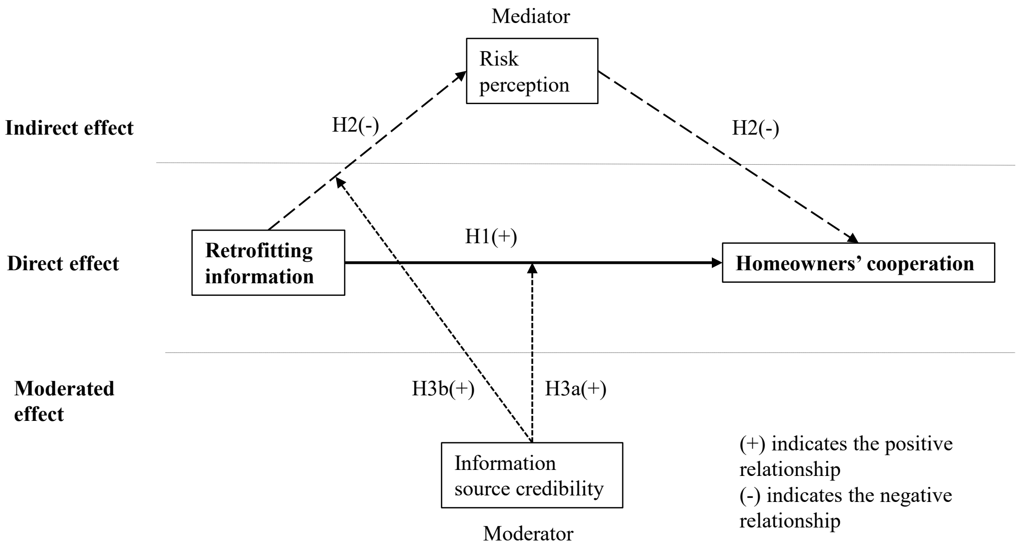

FIG. 4.1 A conceptual framework for hypotheses measurements

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4.3 Methods

4.3.1 Sample and procedure

The empirical survey was conducted in Anhui Province in China. Anhui is one of the provinces where residential energy retrofitting has been carried out relatively early in the HSCW zone. The province has started the promotion and implementation of residential energy retrofitting since 2013 and has encouraged the province-wide retrofitting since 2016. In 2000, at the national level, the Ministry of Housing and Urban-Rural Development of China issued the first regulations on energy conservation in civil buildings. Many provinces in the HSCW zone, including Anhui, have viewed residential quarters built before 2000 as the key targets of renovation at this stage. Meanwhile, considering that the design standard for energy efficiency of residential buildings in the HSCW zone was released in 2010, the authors of this study limited the survey targets to owners of residential buildings built before 2010. Among the completed retrofitting projects, most are the residential quarters built in the 1980s and 1990s, and those built after 2000 are concentrated on buildings of 2001-2005. The residential buildings built during these periods have poor performance in energy efficiency, but have the potential to continue to be used for the next few decades rather than to be demolished. The empirical survey was conducted in six cities in Anhui, and two residential quarters that were built in the 1980s-1990s and in the years between 2001 and 2005, respectively, were selected in each city. Each residential quarter contains 150 to 230 households. Residential buildings in the twelve residential quarters were low-rise concrete-masonry buildings (1-3 storeys) or multi-story concrete-masonry buildings (4-6 storeys). These buildings were designed and constructed using materials with low performance and without any energy efficiency measures (e.g., thermal insulation and ventilation system), and are thus the potential targets of energy retrofitting.

The questionnaires were sent out online. With the popularity of mobile social applications in China, many residential quarters have established their own chat groups in such applications. Basically, every household has at least one representative to join this group to communicate within the residential quarter. All homeowners in the target residential quarters can be contacted via these chat groups. The questionnaire link sent as a message to the chat groups where the twelve residential quarters are located, could be shared by all group members.

The questionnaire is open to the homeowners in all age groups and with different education backgrounds. These respondents were instructed to measure four kinds of variables (including information on retrofitting, information source credibility, risk perception, and homeowners' cooperation). Overall, 708 people completed the online questionnaire within a period of one month (survey date: Spring 2020).

This survey was conducted under some control measures to reduce selection bias. The questionnaire in this study was distributed directly to the target population in order to avoid under-coverage. The questionnaire included a preselecting question which asked respondents to only take part in the survey if they are the owners, instead of tenants or family members of owners. It is also possible that two and over members in one chat group are from one household, and thus some owners did not open the questionnaire when their family members have already filled it out. Meanwhile, the questionnaire link was sent as a message to these chat groups, and some people may have missed it unintentionally. The response rate cannot be accurately determined in this study, but non-response does not necessarily imply a self-selection bias when its reasons are diverse (Amecke, 2012).

This research study conducted the following pre-selection procedure, prior to the analysis to ensure the quality and accuracy of the questionnaires. First, the survey gave an opening question to control over whether respondents are the owners in the target residential quarters. Both tenants and family members of the owners were screened out. Second, this study tested the completed surveys for random response patterns (straight lines) to exclude the respondents who chose the same answer choice over and over again. Third, the respondents who gave mutually conflicting responses were also excluded. For instance, some respondents had no knowledge about building information but thought that building information they received from all sources were totally credible. Finally, 413 were responses remaining for data analysis. The authors regard the sample size of 413 observations to be sufficient for empirical analysis on public engagement in China. For example, Qi et al. (2020) obtained 364 valid questionnaires to analyse the influence of public communication on public acceptance of nuclear energy; and Gong et al. (2020) used 324 samples to explore the factors influencing public acceptance of clean heating.

Table 4.2 shows the demographic data of the survey sample. The majority of the respondents are from the young and highly-educated group (aged under 45 and educated in a college or university), which is also different from the expectation of this survey. Based on the further inquiry with several elderly homeowners, there might be three reasons for the unbalanced distribution of respondents' ages as follows: (1) compared with the elderly, young people spend more time on the Internet using mobile phones, which makes it more likely for them to notice

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the questionnaire link sent as a message; (2) residential energy retrofitting is an emerging topic in China so that elderly people might have little knowledge about retrofitting; and (3) the elderly tend to ask their adult children for help with household decision-making in China, which might also be the case with filling out questionnaires. In fact, the high percentage of respondents with a good educational background in the sample is also related to the ages (under 45) of most respondents. The educational attainment of the survey sample is different compared to those from the distribution in the international context, but is in line with China's stage of educational development. Attributing to University Enrolment Expansion[1], more people have been able to enter a university after graduating from high school since 1999. The admission rate of the college entrance exams has exceeded 50% since 2001, and now it has reached over 90%. This educational policy has also significantly increased the proportion of people under the age of 45 obtaining higher education in China. Nonetheless, the results based on this sample can be generalized due to the important roles of young and highly-educated people in Chinese family decision-making, as mentioned before.

TABLE 4.2 Basic information on participants

Variables		Frequency	Percent
Gender	Male	223	54%
	Female	190	46%
Age	18-45	376	91%
	46-69	32	8%
	Above 69	5	1%
Education	High school or lower	79	19%
	Junior college	243	59%
	Bachelor	81	20%
	Master or above	10	2%
Year	Before 2000	242	59%
	2001-2010	171	41%
Total		413	100%

1 University Enrolment Expansion refers to, the educational reform policy for expanding continuously the enrolment of general colleges and universities based on economic and employment issues since 1999 in the People's Republic of China (i.e., Mainland China).

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4.3.2 Measurement

4.3.2.1 Information on retrofitting

A self-report survey is made to measure the information. This method is a kind of subjective measurement and is used to ask the participants direct questions concerning perceptions, attitudes, or intended actions (Christensen and Knezek, 2008). It is also used to measure other variables including information source credibility, risk perception, and homeowners' cooperation. The participants were first asked to self-evaluate the extent to which they possessed information on retrofitting. For example, the participants were asked directly "How knowledgeable are you about building structure". The information level is measured on a five-point scale from 1 to 5 indicating from 'not knowledgeable at all' to 'very knowledgeable'.

4.3.2.2 Information source credibility

The credibility of information source (IS) was rated by the participants in terms of three kinds of information sources, including:

- social contacts with laypeople (e.g., family, colleagues, and neighbours) (IS1);
- expert knowledge/expert advice (e.g., contractors, designers, energy service experts, and government officials) (IS2); and
- resources published on a public platform (e.g., pilot projects information on a public network platform and databases of energy use) (IS3).

The participants rated the credibility of four categories of information from three types of sources. For example, they were asked, "How credible do you think the building information is, that you received from your social contacts with laypeople". The credibility level is rated on a five-point scale from 1 to 5, indicating from 'not credible at all' to 'very credible'.

4.3.2.3 Risk perception

A six-item scale was used to measure homeowners' risk perception (RP) in energy retrofitting, as shown in Table 4.3. Jia et al. (2020) identified seven risks perceived highly by homeowners who have experienced the energy retrofitting. They did this by measuring the level of their concern about each risk. This study integrated the last two risks related to post-retrofitting maintenance into one question and asked participants' concerns about retrofitting risks based on six questions to measure participants' risk perception. All the items were measured on a five-point scale from 1 to 5, with 1 indicating 'not concerned at all' and 5 indicating 'very concerned'.

TABLE 4.3 Risk perception items adapted from Jia et al. (2020)

Risk No.	Items	Risk perception No.
R1	Unqualified building materials	RP1
R2	Lack of construction skills	RP2
R3	Moral hazard	RP3
R4	Poor quality of old residential buildings themselves	RP4
R5	Poor safety management	RP5
R6	Inadequate maintenance	RP6
R7	Difficulties in post-retrofit repair	

4.3.2.4 Homeowners' cooperation

As shown in Table 4.4, the level of homeowners' cooperation (HC) was measured by five items. According to the field survey, this study summarized the homeowners' rights and obligations in energy retrofitting. Five items of homeowners' cooperative behaviours originate from these homeowners' roles listed in Table 4.4. Participants were asked the likelihood that they would take these actions if their homes were planned by the government to be renovated. A five-point scale from 1 to 5 was used to measure homeowners' cooperative behaviours, indicating from 'totally unlikely' to 'very likely'.

TABLE 4.4 Items for measuring the level of homeowners' cooperation

Homeowners' rights and obligations in energy retrofitting	Items of homeowners' cooperation
Homeowners can decide whether to approve the energy retrofit of their home, and most homeowners' approval (more than 2/3) is required.	HC1: Approve the energy retrofitting of their homes.
Homeowners can first give some opinions about retrofit items to the government staff. Then, when retrofit items are posted, they can also put forward some advice. During the period of posting the retrofit schemes, homeowners can give feedback to the government staff.	HC2: Accept all the renovation plans arranged by the government, including doors and windows, external walls, roofs and so on.
Homeowners need to cooperate with the government staff to clean the spot before the on-site construction.	HC3: Cooperate with the government and other project personnel to remove the obstacles in the construction site, including the illegal construction in the community and on the roof, etc.
Homeowners can supervise contractors' work and can also give some advice about retrofit construction.	
Homeowners need to cooperate with contractors in construction work.	HC4: Cooperate with the construction personnel and follow their schedule, plan, site planning, and material placement arrangements.
Homeowners can participate in the checking and acceptance of retrofit projects.	
Homeowners need to maintain the renovated buildings to keep the good performance of installed retrofit technologies.	HC5: Maintain the post-retrofitting residential quarters under the arrangement of the government and property management enterprises.

4.3.3 Data analysis

First, this study conducted descriptive and correlation analysis using all the variables to confirm that there were sufficient variations of variables and if certain variables were correlated. Moreover, descriptive analysis was used to show the average levels of information, risk perception, and homeowners' cooperation.

Second, structural equation modelling (SEM) was used with AMOS 23.0 to verify hypotheses 1 and 2. Six latent variables (including BI, RB, RT, RS, RP, and HC) are involved in hypotheses 1 and 2, and this study examined the direct and indirect effects among these variables. Compared with other multivariate analysis methods, SEM is more useful to deal with the variables that cannot be measured directly and to estimate multiple inter-dependent relationships among these variables (Kline, 2015). There are two components in SEM: measurement model, and structural model. Each measurement model is used to elaborate one latent variable by employing several observable variables, while the structural model conveys the interrelated dependence relationships among the latent variables. A large sample size is necessary for SEM. Kline (2015) gave a minimum sample size of 200, while Raykov and Marcoulides (2012) suggested at least 10 observations per indicator variable in the model. The number of samples in this study is 413 and there are 14.75 cases per indicator variable, which is considered to be sufficient data points.

Third, linear multiple regression methods with SPSS 23.0 were used to test hypothesis 3. RP and HC were linked to four information variables (BI, RB, RT, and RS) respectively to form four independent models, and three variables of IS credibility related to each information variable were imported into the corresponding information model in sequence. This study centred the variables of information and IS credibility before constructing interactive items so as to reduce multi-collinearity. The multiple linear regressions were employed to examine the moderating effect of information source credibility on the strength of direct relationships between information and HC. HC was the dependent variable, and there were three independent variables including information, IS credibility, and the interaction parameter between information and IS credibility. Then, the moderation roles of IS credibility on the strength of the indirect effect between information and HC via RP were tested by the PROCESS procedure written by Hayes (2017), in which a 5000 resampling bootstrap was adopted. In the procedure, the model number was first set to 8. HC, information, RP, and IS credibility were moved to this procedure as outcome variable, independent variable, mediation variable, and moderation variable, respectively.

4.4 Results

4.4.1 Descriptive analysis

Descriptive statistics and correlations of all variables are shown in Table APP.C.1 in Appendix to Chapter 4. The participants were generally less informed of all types of information (mean<3) and also had some concern about retrofitting risks (mean=3.6). These participants expressed a relatively positive attitude towards cooperation (mean=3.51). No matter what kinds of information they received, the participants viewed expert knowledge and published resources (mean>3 and even 3.5) as more credible information sources than social contacts with laypeople (mean<3). *Risk perception* was positively correlated with *building information* but negatively correlated with *information on retrofitting service*. *Homeowners' cooperation* was positively correlated with information on *retrofitting benefits* and *retrofitting service*, but negatively correlated with *risk perception*.

4.4.2 Structural equation model specification

According to the theoretical expectation, the structural equation model was generated. The resulting model is shown in Figure 4.2, which presents the path coefficients ranging from 0.57 to 0.85 for the effects of observed variables on latent variables. It is suggested that the observed indicators can represent the latent constructs.

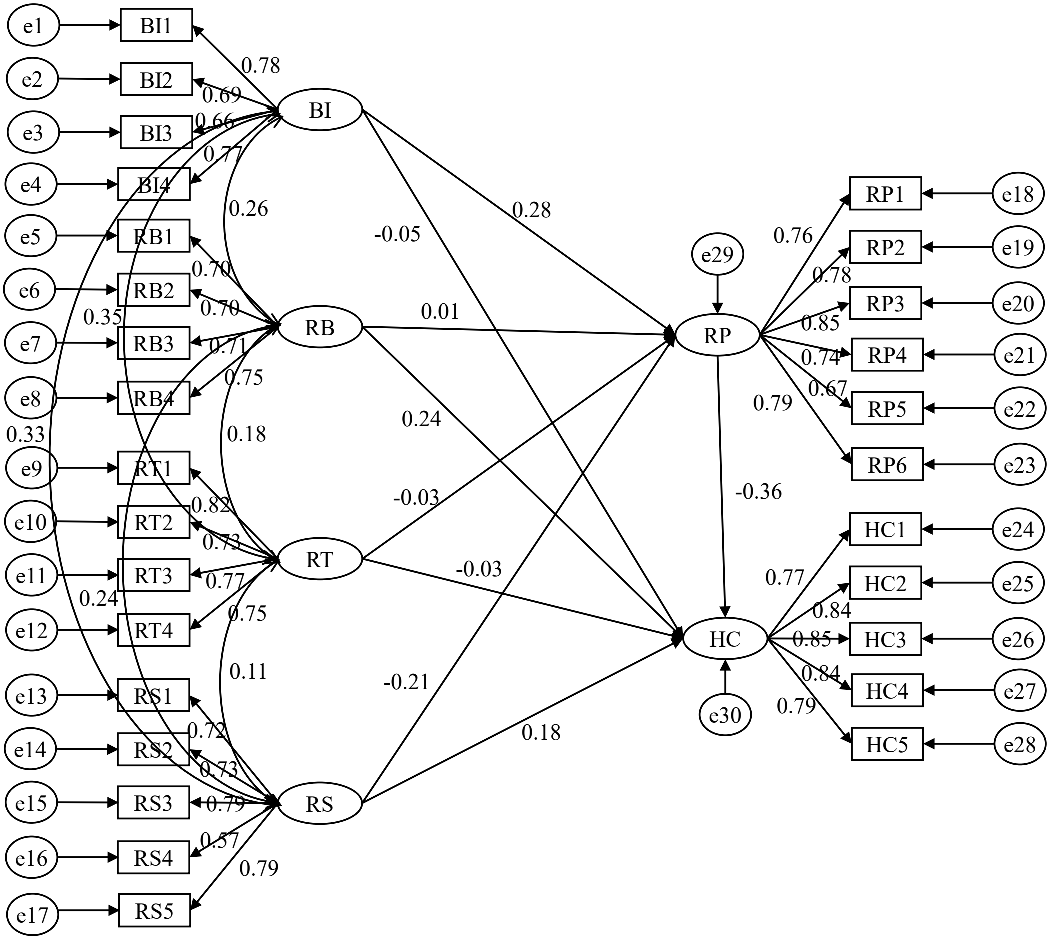

FIG. 4.2 Derived structural equation model

The overall model fit was evaluated and the test results are given in Table 4.5. The coefficient of χ^2/degree of freedom is 2.137, which is lower than the criteria. Based on the outputs of AMOS 23.0, Table 4.5 also presents the values of five main indexes recommended by Hu and Bentler (1998) and lists the corresponding traditional cut-off values suggested by Marsh et al. (2004). As shown in Table 4.5, the fit between the theoretical model and data is acceptable, and thus, the overall model for relationships between information, risk perception, and homeowners' cooperation is supported.

TABLE 4.5 Goodness-of-fit (GOF) indexes

Fit index	χ^2/degree	CFI	IFI	TLI	RMSEA	SRMR
Value	2.137	0.932	0.933	0.924	0.053	0.0468
Criteria	<3	>0.9	>0.9	>0.9	<0.08	<0.05

Note: CFI=comparative fit index; IFI=incremental index of fit; TLI=Tucker-Lewis index; RMSEA=root mean square of approximation; SRMR=standardized root mean square residual.

In order to assess the internal reliability of latent variables, Composite Reliability (CR) values and Average Variance Extracted (AVE) values are provided in Table 4.6. CR measures the consistency of a set of latent construct indicators in the measurement, and the values above 0.8 can be considered adequate for the reliable construct (Koufteros, 1999). AVE detects the true representativeness of latent construct variables and is a supplementary measure for construct reliability (Koufteros, 1999). AVE values are suggested to be more than 0.5 for any construct (Bagozzi and Yi, 1988). Table 4.6 presents six latent variables with CR being over 0.8 and AVE being over 0.5, which indicates good internal consistencies of all latent variables.

TABLE 4.6 Composite Reliability and Average Variance Extracted

Dimension	CR	AVE
BI	0.813	0.522
RB	0.807	0.512
RT	0.850	0.587
RS	0.843	0.522
RP	0.895	0.589
HC	0.910	0.669

Note: BI=Building information; RB=Retrofitting benefits; RT=Retrofitting technology; RS=Retrofitting service; RP=Risk perception; HC=Homeowners' cooperation.

The parameter estimates of direct paths derived from the structural equation model are shown in Table 4.7. *Information on building* and *retrofitting service* has significant impacts on *risk perception*. Risk perception is negatively correlated with *homeowners' cooperation*. Meanwhile, H1, the direct effect of information on homeowners' cooperative behaviours, is also examined. *Homeowners' cooperation* is positively contributed by *information on retrofitting benefits* and *retrofitting service*.

TABLE 4.7 Regression weights of the direct path

Path	Standardized Estimate	S.E.	C.R.	P
BI→RP	0.281	0.072	4.111	***
RB→RP	0.013	0.078	0.208	0.835
RT→RP	-0.030	0.071	-0.497	0.619
RS→RP	-0.214	0.083	-3.471	***
RP→HC	-0.362	0.048	-6.469	***
BI→HC	-0.046	0.058	-0.722	0.470
RB→HC	0.241	0.064	4.143	***
RT→HC	-0.032	0.055	-0.576	0.565
RS→HC	0.176	0.067	3.034	0.002

*Note: "***" indicates P<0.001; BI=Building information; RB=Retrofitting benefits; RT=Retrofitting technology; RS=Retrofitting service; RP=Risk perception; HC=Homeowners' cooperation.*

Table 4.8 provides the bias-corrected bootstrapping results to examine H2 of the mediating role of risk perception. A 5000 resampling bootstrap was used to support the mediating role of *risk perception* between *building information* and *homeowners' cooperation* and between *positive information on retrofitting service* and *homeowners' cooperation*.

TABLE 4.8 Bootstrap testing of the mediating role of risk perception

Path	Standardized Estimate	SE	Bias-corrected 95%CI		
			Lower	Upper	P
BI→RP→HC	-0.102	0.025	-0.158	-0.059	0.000
RB→RP→HC	-0.005	0.022	-0.048	0.039	0.836
RT→RP→HC	0.011	0.021	-0.031	0.054	0.560
RS→RP→HC	0.077	0.023	0.036	0.127	0.000

Note: BI=Building information; RB=Retrofitting benefits; RT=Retrofitting technology; RS=Retrofitting service; RP=Risk perception; HC=Homeowners' cooperation.

4.4.3 Testing the moderating role of information source credibility on direct relationships between information and homeowners' cooperation

The moderation testing of information source credibility was performed in the case of different sources and different kinds of information. The testing results are used to verify H3a and are shown in Table 4.9.

TABLE 4.9 Moderating results in direct paths

	Path	IS1	IS2	IS3
Main effect	BI→HC	-0.027	-0.023	-0.016
	RB→HC	0.196**	0.190**	0.217**
	RT→HC	-0.017	-0.018	-0.003
	RS→HC	0.233**	0.223**	0.222**
Moderation effect	BI*IS→HC	-0.052	-0.056	0.051
	RB*IS→HC	0.075	0.113*	0.156**
	RT*IS→HC	-0.164**	-0.038	-0.074
	RS*IS→HC	0.074	-0.072	0.030

*Note: "**" and "*" indicate $p<0.01$ and $p<0.05$, respectively; BI=Building information; RB=Retrofitting benefits; RT=Retrofitting technology; RS=Retrofitting service; HC=Homeowners' cooperation; IS=Information source; IS1=Social contacts with laypeople; IS2=Expert knowledge/expert advice; IS3=Resources published on a public platform.*

As shown in Table 4.9, the credibility of both *expert knowledge* and *published resources* moderates significantly the strength of the relationship between *retrofitting benefits* and *homeowners' cooperation*. Figure 4.3 and Figure 4.4 provide the slope test further to support the moderation effect of the credibility of these two sources. The direct relationships between *retrofitting benefits* and *homeowners' cooperation* are significant only under the high credibility of the sources.

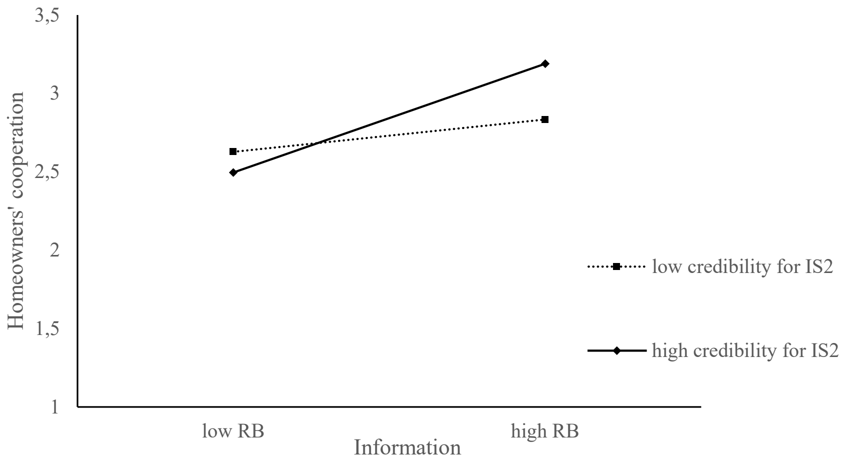

FIG. 4.3 Interactive effect of RB and IS2 credibility on HC

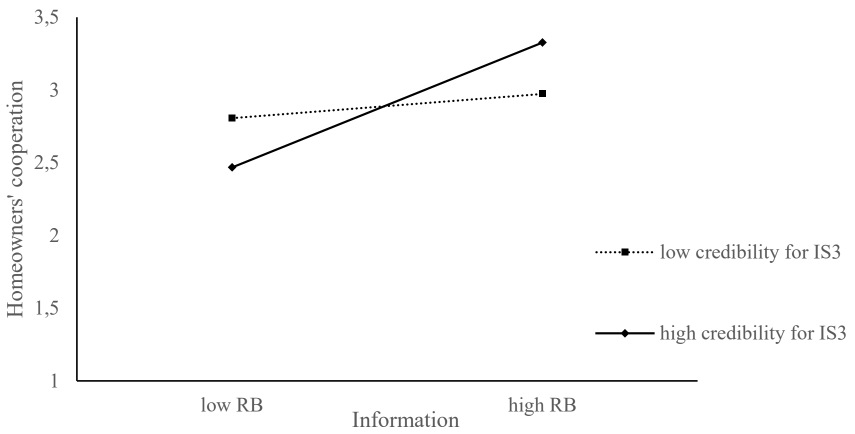

FIG. 4.4 Interactive effect of RB and IS3 credibility on HC

According to the results of the moderation effect in Table 4.9, the interactive effect of the credibility of *social contacts with laypeople* and *information on retrofitting technology* significantly influences *homeowners' cooperation*. Figure 4.5 provides further support for the interactive effect: increased *information on retrofitting technology* has a more significantly negative impact on *homeowners' cooperation* in the case of high credibility of *social contacts with laypeople*.

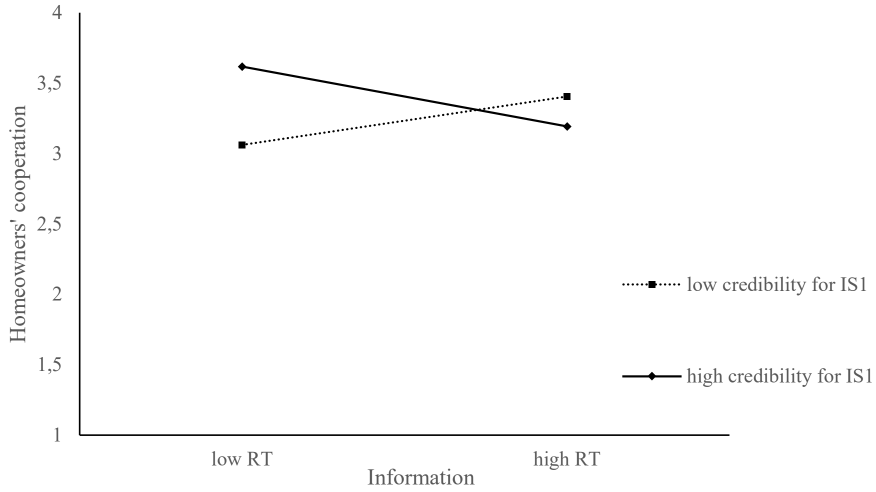

FIG. 4.5 Interactive effect of RT and IS1 credibility on HC

4.4.4 Testing the moderating role of information source credibility on indirect relationships between information and homeowners' cooperation via risk perception

Based on a 5000 re-sampling bootstrap in PROCESS, the moderating role of information source credibility in the mediating effect of risk perception is examined to validate H3b. The testing results are shown in Table 4.10.

Table 4.10 provides the support for the moderating role of source credibility in the indirect influence of *building information* on *homeowners' cooperation*. The mediation effect of *risk perception* is moderated by the credibility of both *social contacts with laypeople* and *expert knowledge* significantly. The mediation effects of *risk perception* are significant only in the case of high credibility (+1 SD from the mean) of *social contacts with laypeople* and *expert knowledge*.

The moderating role of source credibility in the indirect effect of *retrofitting technology information* can also be supported by the results shown in Table 4.10. The credibility of *social contacts with laypeople* can moderate the mediation effect of *risk perception* between *information on retrofitting technology* and *homeowners' cooperation* significantly. The mediation effect of *risk perception* is significant only when the credibility of *social contacts with laypeople* is high.

TABLE 4.10 Moderated mediation results

Mediation path	Moderator		Effect	SE	BootLLCL	BootULCL
BI→RP→HC	IS1		-0.043	0.018	-0.083	-0.009
		High(+1 standard deviation)	-0.112	0.029	-0.177	-0.062
		Low(-1 standard deviation)	-0.018	0.026	-0.070	0.032
	IS2		-0.061	0.018	-0.099	-0.030
		High(+1 standard deviation)	-0.127	0.030	-0.195	-0.077
		Low(-1 standard deviation)	0.006	0.023	-0.040	0.056
	IS3		-0.024	0.019	-0.066	0.012
RB→RP→HC	IS1		0.026	0.019	-0.010	0.064
	IS2		0.013	0.019	-0.022	0.052
	IS3		0.018	0.020	-0.022	0.059
RT→RP→HC	IS1		-0.067	0.021	-0.111	-0.030
		High(+1 standard deviation)	-0.078	0.027	-0.134	-0.030
		Low(-1 standard deviation)	0.045	0.027	-0.006	0.101
	IS2		-0.036	0.022	-0.080	0.007
	IS3		0.004	0.020	-0.036	0.046
RS→RP→HC	IS1		0.042	0.018	0.011	0.081
		High(+1 standard deviation)	0.102	0.028	0.053	0.165
		Low(-1 standard deviation)	0.017	0.027	-0.038	0.070
	IS2		0.048	0.019	0.015	0.088
		High(+1 standard deviation)	0.110	0.031	0.055	0.175
		Low(-1 standard deviation)	0.010	0.028	-0.046	0.065
	IS3		0.050	0.026	0.003	0.106
		High(+1 standard deviation)	0.095	0.031	0.042	0.164
		Low(-1 standard deviation)	0.016	0.028	-0.039	0.072

Note: BI=Building information; RB=Retrofitting benefits; RT=Retrofitting technology; RS=Retrofitting service; RP=Risk perception; HC=Homeowners' cooperation; IS1=Social contacts with laypeople; IS2=Expert knowledge/expert advice; IS3=Resources published on a public platform.

Table 4.10 supports the moderating role of source credibility in the indirect influence of *positive information about retrofitting service* on *homeowners' cooperation*. The moderating roles of the credibility of all three information sources, namely *social contacts with laypeople*, *expert knowledge*, and *published resources*, in the mediation effect of *risk perception* are significant. The indirect effects between *positive information about retrofitting service* and *homeowners' cooperation* via *risk perception* are significant only when the source credibility is high.

4.5 Discussion

4.5.1 Limited role of building and technology information under the current environment of energy efficiency

The findings of this study show that there is no significant direct relationship between building information and homeowners' cooperation. Currently, there is no reasonable and uniform standard for the energy consumption of old residential buildings in China, especially those that were built before 2000. Even if household energy consumption is very considerable, these homeowners might have no consciousness about the necessity of energy retrofitting due to the lack of the baseline of building energy consumption. Moreover, the average household electric power price in China was only $0.084 per kilowatt-hour, a price that was much lower than some developed countries such as Germany, Italy, the UK, and Japan, with electricity prices of over $0.2 per kilowatt-hour, based on 2016 data. The usage of electricity with low prices is considered by homeowners in the HSCW zone to be able to compensate for poor building thermal insulation systems to ensure a sense of living comfort. These situations in China are consistent with the study results of Palmer et al. (2013) in two respects: (1) energy spending does not put much pressure on household finances due to low energy prices; and (2) information on the energy performance of homes alone is insufficient to drive homeowners to renovate their homes.

It is found out that the provision of retrofitting technology information does not contribute significantly to homeowners' cooperation. Such insignificant influence is probably due to the limitations of selection on retrofitting technology in China. In general, technology options provided for homeowners are standardised retrofit packages and are limited within a scope set by the local government and designers in advance in China. It is likely, that these standardised retrofitting technologies are not what homeowners need (Lo, 2015). As a result, the information relevant to these technologies cannot motivate homeowners to be involved actively in retrofitting projects. This problem results from the current retrofitting financing mode in China. In the case that governments cover all the expenses, the boundaries of retrofit packages are determined by the available government financial support (de Feijter et al., 2019).

4.5.2 Impetus of homeowners' cooperation: benefits and good service

It is confirmed that increased information on retrofitting benefits can facilitate directly homeowners' cooperation. At present, the local government is the main investor of energy retrofitting of residential buildings in China. The reduced household spending without any capital input is still attractive to homeowners. Direct economic benefits underwritten by the government are necessary for the homeowners to accept the retrofitting solutions (Li et al., 2013). Moreover, with the improvement of living standards, homeowners tend to focus more on living comfort, which can explain the rapid growth in building power consumption in recent years in China but is, in turn, also a great motivator of participating in energy retrofitting to homeowners. Even in the study of Pettifor et al. (2015), the maintenance of a level of comfort was viewed to be more relevant to homeowners than financial motivators. Similarly, Gram-Hanssen (2014) also supported that increased knowledge of all energy efficiency benefits could motivate homeowners to improve the energy efficiency of their homes.

Our survey confirms that, increased positive information about retrofitting service is conducive to the improvement of homeowners' cooperation, both directly and indirectly. The information on retrofitting service in this study covers some practical issues, mainly involving contractors' construction service and homeowners' control over construction. In China, homeowners are rarely involved in the search for contractors, material procurement, and construction planning. Positive information enables homeowners to realize the high reliability of contractors and the high feasibility of supervising the construction work, further reducing their perceived uncertainty due to their low involvement in retrofitting construction. Our result is actually in line with the finding of Christensen et al. (2014) that homeowners consider the practical issues concerning homeowners' ability to cope with retrofitting and the reliability of tradespersons as the main concern for retrofitting or not. Meanwhile, the information covering practical issues also contributes to the decrease in homeowners' worries and anxieties (Zundel and Stieß, 2011).

4.5.3 Barriers to homeowners' cooperation: safety concern and hard-to-understand technology information

The indirect effect of building information on homeowners' cooperation is significant but is negative due to its amplification effect on risk perception. This might be attributed to the common reality of the poor structural quality of old residential buildings. Poor design and construction is indeed a common problem of building stock in China (Baldwin et al., 2018). In particular, housing commercialization in the 1980s and 1990s led to a nationwide boom of urban residential buildings in China, but there was no requirement for housing quality, due to the lack of laws and standards. For example, the "Construction Law", the highest-level law regulating the quality of housing construction in China, was issued in 1997, and "Regulations on the Quality Management of Construction Projects" was officially approved and implemented by the State Council in January 2000. The majority of survey participants in this study are from the residential quarters built before 2000 (i.e., in the 1980s and 1990s). The reality of this information leads homeowners to doubt the stability of the building structure in the retrofitting process. People's exposure to information on the risky situation can trigger higher levels of their risk perception (Lindell and Hwang, 2008; Lindell and Perry, 2012).

Negative effects of technology information on homeowners' cooperation directly and indirectly are increased significantly under the influence of the high credibility of social contacts. It can come down to the features of technology information, namely, their complexity and them being difficult to understand. Much of the information about technology and equipment of building energy efficiency involves complicated terminologies and is thus poorly understood by homeowners (Syal et al., 2014). Similarly, the knowledge of the laypeople in homeowners' social networks is also influenced, which leads to their misunderstanding of technology to some extent. The information from social networks is viewed as a complement to specific technical information and plays a decisive impact on homeowners' decisions (Bartiaux et al., 2014). Inaccurate or biased information from social networks leads homeowners to have more concern about risks about retrofitting technology and also prevents homeowners from accepting retrofitting.

4.5.4 Thoughts on differences of information sources

The findings support that, high credibility of information sources is a prerequisite to the significant direct or indirect effect of retrofitting information on homeowners' cooperation. Still, the moderating effect of source credibility, such as published resources providing building information and social contacts providing retrofitting benefits, cannot be reflected in survey results in some cases, due to the limitation of the availability of information. The importance of the Internet as an information source is dependent on the available online building analysis tools (Novikova et al., 2011b). However, informative online instruments, such as a building energy consumption database and energy performance certificates, are rarely found in China. In this case, it is difficult for homeowners to extract the particular building information they need from published resources.

Similarly, few retrofitting benefits can be perceived by laypeople especially in the HSCW zone of China. Homeowners who have benefitted from retrofitting in this region are limited due to the slow development of residential energy retrofitting. Moreover, as mentioned by Matschoss et al. (2013), apartment owners rarely monitor their energy consumption and expenditure. In other words, few homeowners, even those who have experienced energy retrofitting, are familiar with retrofitting benefits like energy and financial savings. As a result, potential consumers of energy retrofitting can only receive very limited information on retrofitting benefits from their social contacts with laypeople, even if Bartiaux et al. (2014) considered information transferring through social networks as a characteristic of retrofitting.

4.6 Conclusions and policy implications

There is an increased attention to energy retrofits of residential buildings especially in the HSCW zone in China. Homeowners' cooperation is the key to the smooth implementation of retrofitting projects in order to speed up the retrofitting process. This study contributes to the body of knowledge by considering information provision into as an approach to improving homeowner' cooperation in the whole process of retrofitting projects. This study determines the direct relationships between four kinds of retrofitting information and homeowners' cooperation, the indirect relationships via risk perception and the influences of information source credibility as a moderator on these relationships.

The results show the important roles of both retrofitting benefits and positive information about retrofitting service in motivating homeowners to cooperate. The government should value the diffusion of information on retrofitting benefits and service of information in the general public domain. In consideration of the importance of high source credibility and homeowners' general recognition of expert knowledge and published resources, the government must make pilot retrofitting projects more transparent. More retrofitting benefits are disseminated at public platforms in the way of achievements demonstration. Meanwhile, the communication and exchanges between pilot projects and the local community should be strengthened to make retrofitting service information accessible to homeowners.

The objective information on some quality problems in the building itself leads to the increase in homeowners' concern about the safety during the retrofitting, thereby reducing their enthusiasm for cooperation. The government should make more detailed and strict provisions of quality and structure of the potential renovated buildings to ensure retrofitting safety. This positive information about building quality (e.g., the potential to reinforce the buildings or to deal with cracks and water seepage) should be correspondingly stressed in the published retrofitting plans to reduce homeowners' risk perception. Furthermore, some local governments have facilitated the adoption of energy consumption databases of public buildings, but databases for residential buildings are seldom mentioned. The government should pay more attention to the establishment of energy consumption databases of residential buildings, and make them available to the public.

The technology information on the standardised retrofitting packages has a minimal influence on homeowners' cooperative behaviours, but homeowners' cooperation is significantly hindered by the increase of technology information under the high credibility of social contacts with laypeople. The government should encourage appropriately personalized retrofitting projects. It requires a good understanding of the context of homeowners' everyday life so that the government can carry out retrofitting projects based on homeowners' actual needs within the financial limits. However, the fundamental solution is that the government needs to diversify the channels of retrofitting investment and social capital. It is also suggested that the government should provide technical information in a form that can be easily understood by homeowners. In other words, the provided technical information needs to be adapted to homeowners' state of knowledge to make sure of their proper understanding.

This study has shown that homeowners' cooperation is closely influenced by risk perception and retrofitting information. Still, other factors affecting homeowners' cooperation were overlooked, such as homeowners' reputation among the neighbours (Zundel and Stieß, 2011), and personal norms referring to the feelings of moral obligations (Kastner and Stern, 2015). These factors about personal values can be incorporated into the model of homeowners' participation in future. Besides, given the unique government-led retrofitting model in China, this study does not consider financial constraints to homeowners' cooperation that has been mentioned generally in the international context (Biekša et al., 2011; Caputo and Pasetti, 2015; Dahlhausen et al., 2015). Considering that homeowners' investment is the key to maintaining the continuous development of energy retrofitting, future research can focus on how to develop effective economic measures (e.g., loans and subsidies) to attract more funds from homeowners, instead of relying solely on government finance.

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5 Strategies for Mitigating Risks of the Government-led Energy Retrofitting Projects in China:

a Transaction Costs Perspective

Submitted for review.

ABSTRACT Residential energy retrofitting projects in the hot summer and cold winter (HSCW) zone of China are exposed to various risks. These risks are related to project activities, incurring transaction costs (TCs) (e.g., search, negotiation, and monitoring costs). The Chinese government is the leader of project implementation and is responsible for project planning, organization, and coordination. TCs hinder government's execution of risk-related project activities, thus preventing the government from running projects effectively. Such restrictions on government's behaviours, in turn, increase the probability of risk occurrence. Drawing on the transaction cost economics (TCE), this study proposes a theoretical framework for understanding the barriers (e.g., asset specificity, uncertainty, and frequency) to government performing project activities and mitigating risks. An artificial neural network (ANN) is applied to verify the hypotheses. The results support the experience and operation maturity in project activities, costs and time restrictions, and the immature retrofitting market as important hindrances to government execution of risk-related activities. Considering the varying roles of the government in reducing different risks, this study concludes by providing policy recommendations specific for each of the risks. Policy measures to alleviate activity barriers and mitigate risks, include popularizing information, promoting building diagnosis, encouraging material and personnel certification, etc.

KEYWORDS Energy retrofitting of residential buildings; Government's behaviours; Risk mitigation; Transaction cost; Artificial neural network

5.1 Introduction

Worldwide, energy retrofitting of urban residential buildings has been recognized as an approach to energy conservation and emission reduction in order to achieve urban sustainability. China is no exception. Efforts have been made to improve the energy efficiency of existing residential buildings in China since 2006. Still, energy retrofitting progress of residential buildings in the hot summer and cold winter (HSCW) zone is slow, which can be attributed to the hindering effects of the risks on energy retrofitting process (Jia et al., 2021). Risks are characterised by uncertainty and negative impacts on project objectives (Chia, 2006). Residential energy retrofitting in the HSCW zone of China is exposed to various risks with respect to homeowners' willingness and cooperation performance, technical standards, expertise of designers and contractors, construction management, post-retrofitting maintenance, etc. (Jia et al., 2021).

Risk management is key to effective project management and aims at the achievement of project objectives (Lavanya and Malarvizhi, 2008). The achievement of project goals and objectives is based on the completion of the specific tasks and activities in each stage (Munns and Bjeirmi, 1996). The risks exist in the whole process of retrofitting projects in China and are related to various project activities, such as feasibility assessment, formulation of technical standards, negotiation with homeowners, selection of design and construction companies, and monitoring the retrofitting construction (Jia et al., 2021). Aside from production costs of retrofitting projects, some extra costs, namely transaction costs (TCs), are hidden in these activities, including search costs, assessment costs, negotiation costs, monitoring costs, etc. In fact, TCs are widely present in project activities in different phases of retrofitting projects, and costs of due diligence, negotiation costs, and monitoring costs are the main categories of TCs in energy retrofitting projects (Kiss, 2016). High TCs is an important obstacle to the application of energy-saving technology and the implementation of retrofitting projects (Kiss, 2016). TCs arising from risk-related project activities lead to the increase in TCs in the process of retrofitting projects, further impeding the project implementation.

Risks and the related TCs can be viewed as barriers to government running retrofitting projects. The local government-led retrofitting is the most common model in China, with the responsibility of the local government of planning, organization, supervision, and coordination (Liu et al., 2015; Wang et al., 2015). As the leader and sponsor of retrofit projects, the local government is involved in the whole process of projects and is responsible for performing many project activities including risk-related activities. For example, the risks about the ability of designers and contractors are associated with the activity of selecting designers and contractors, and the government makes decisions for this selection. The government is the main bearer of TCs related to risks in residential energy retrofitting projects (Jia et al., 2021). TCs restrict the decision-making or behaviours of the government in these risk-related project activities. This requires find out the key factors causing the increase in these risk-related TCs to enable the government to run effectively the retrofitting project.

Improving the project running of the government is also an approach to risk management. Government performance in risk-related project activities, in turn, affects the probability of risk occurrence. For instance, if the government can select the qualified designers and contractors, there might be less probability of the risks about the ability of designers and contractors. The decrease in occurrence probability is one of the keys to risk management (Xia et al., 2017). In fact, the government itself plays a great role in risk management in residential energy retrofitting projects. Homeowners' attitudes rely heavily on government's publicity of retrofitting benefits (Ouyang et al., 2011). Energy saving performance and standards of material quality and energy efficiency coefficient need to be controlled by the government (Liu et al., 2015; Zhao and Lou, 2013). For this reason, risk management in residential energy retrofitting projects in China relies on policy support to a large extent.

Few studies consider TCs and government's roles in risk analysis and risk management of residential energy retrofitting projects. The previous studies focus on the risks related to the energy efficiency gap and investment benefits (Bao et al., 2012; Biekša et al., 2011; Caputo and Pasetti, 2015; Dahlhausen et al., 2015; Li, 2009; Lo, 2015), and only consider energy-savings insurance to transfer risks (Mills, 2003; Mills et al., 2006). Moreover, the existing studies ignore the government's roles in the implementation of retrofitting projects, and mainly highlight government involvement in the promotion of energy retrofitting market, such as the operation of energy retrofitting market (Atkinson et al., 2009; Pardo-Bosch et al., 2019), technology innovation (Cai et al., 2009; Friedman et al., 2014; Shaikh et al., 2017), private capital entry (Krarti et al., 2017; Mikulić et al., 2016), and homeowners' acceptance (He et al., 2019; Palmer et al., 2013).

In order to smoothen the implementation of residential energy retrofitting projects in the HSCW zone of China, this study aims to investigate the factors raising the risk-related TCs that prevent government from running projects and provide the government with policy suggestions for risk mitigation of retrofitting projects. First, a theoretical framework containing three hypotheses based on transaction cost economics (TCE) is established to explore barriers to government performing risk-related project activities. Second, this study develops a series of indicators in four aspects of asset specificity, uncertainty, frequency, and behavioural intentions towards the risk-related project activities and conducted a questionnaire survey for empirical analysis. Third, both exploratory factor analysis (EFA) and artificial neural network (ANN) are adopted to verify the influence of risk-related TC factors on performing project activities. Finally, policy suggestions are proposed by combing government's responsibility in risk management to mitigate risks of retrofitting projects.

5.2 Literature review

5.2.1 Government role in energy retrofitting projects

Governments' involvement is necessary for the successful implementation of large-scale energy retrofitting projects especially in the sector of residential buildings (Krarti et al., 2017). The promotion and application of residential energy retrofitting fail to be done well without guidance and encouragement of governments (He et al., 2019). In particular, Private homes in China are mainly passively renovated under the leadership of the local government. Residential energy retrofitting in China focuses on old multi-owner apartment buildings. Homeowners own their apartments individually and share ownership of the common parts of a building, but the land is owned by the state. Government finance is the main source of retrofitting funding in China (Liu et al., 2015; Yan et al., 2011). As the leader and sponsor of retrofit projects, the government in China does not only act on the retrofitting market to promote the demand and supply for energy-efficient products and service, but also makes decisions for the overall implementation and task actions of each retrofitting project.

The government plays an important role in the implementation of residential retrofitting projects in China. Jia et al. (2021) divided the implementation process of residential retrofitting projects in the HSCW zone of China into five stages and listed the main project tasks in each stage (shown in Table 5.1). Table 5.1 summarizes the project activities that need to be performed by the government departments in each stage. The Chinese government is involved in the whole process of retrofitting projects. Government's decision-making and behaviours in these project activities to a large extent determine whether the project tasks at each stage can be effectively accomplished.

TABLE 5.1 Retrofitting project stages and activities involving the government in China

Stage	Project Task	Project activities involving government departments
Regional survey and project setup	Make the 5-year plan for renovation	– Build a database of old residential quarters in each district and county – Make the 5-year plan for renovation based on the real conditions
	Make the annual plan for renovation by asking for homeowners' opinions	– Conduct the survey among homeowners for approval – Make the renovation plans for next year
	Program review	– Do the detailed field investigation to check the feasibility of renovation plans – Assign the renovation tasks
	Go through the formalities for preliminary work	– Go through the formalities for preliminary work (e.g. project planning and environmental evaluation).
Project design and budget estimation	Determine the design and supervision company	– Determine the design and supervision company through public bidding
	Design the preliminary retrofitting plan and prepare budget estimation	– Organize homeowners' representatives and designers to hold the meeting to reach an agreement on retrofitting design
Construction bidding and fund appropriation	Perform the detailed design and budget	– Compile the bill of quantities in accordance with the preliminary retrofitting plan and budget estimation – Audit the budget reported by the departments at a lower level and issue the audit report.
	Carry out construction bidding	– Determine the construction company through public bidding
	Allocate retrofitting funds	– Allocate the funds for the renovation of old residential quarters – Audit renovation projects, and submit the audit results
On-site construction	Clean the spot before the site construction	– Organize homeowners to demolish illegal buildings in the residential quarters and to clean up the clutter and vegetable plots – Organize units of power supply, water supply and gas supply to clean up the pipe of retrofitted residential quarters
	Training for site construction	– Organize the design company and relevant professional staff to provide trainings for project managers, managers on site, and supervisors
	Site implementation	– Guide, inspect and supervise the construction work – Respect fully public opinions
Inspection, acceptation, and use	Inspect and accept the retrofitting projects, and settlement auditing	– Organize finance, audit and fire departments, neighbourhood offices, and the representatives on behalf of the households to check the project quality and funds payment – Help perfect the formalities of takeover – Settlement audit
	Management after retrofitting	– Improve the corresponding management systems to maintain the retrofitting achievements

5.2.2 Transaction costs

TCs are different from production costs and are the economic equivalents of friction in physical systems (Williamson, 1985). TCs are generally composed of search and information costs, bargaining and decision costs, contract cost, monitoring costs, enforcement costs, and switching costs (Dahlman, 1979). Institutions, the rules that frame people's behaviours in terms of economy, society, and policy, play a key role in TCs (North, 1990). Institutions were divided by North (1990) into two levels of formal and informal ones. Williamson (1998) viewed these two levels as institutional environment referring to legal, social and political rules, and institutional arrangements involving governance structure. An effective project governance framework is necessary for effective risk management, which is related to the balance between costs and benefits (Bannerman, 2008). The appropriate governance structure can be achieved by means of economizing TCs (Winch, 2001).

Project governance structure involving the policies, processes, standards, procedures, and guidelines is a framework for project running and government performing project activities in energy retrofitting projects. Risk management is also implemented under such governance structure. TCs related to an institution have two components: the costs of forming an institution and the costs of conducting exchange within an institution (Nolan and Trew, 2015). This study only regards TCs as exchange costs within an institution, namely government's extra expenses (e.g. searching, learning, and monitoring costs) on performing the risk-related activities in the residential energy retrofitting projects. TCE suggests that three important characteristics in a transaction raise TCs: degree of asset specificity, uncertainty, and transaction frequency (Williamson, 1998, 2005, 2008). These three transaction characteristics are also considered by this study as the dimensions of risk-related TC barriers to government running projects.

5.2.2.1 Asset specificity in project activities related to risks

Asset specificity refers to a "specialised investment that cannot be redeployed to alternative uses or by alternative users without a loss in productive value" (Williamson, 1996). Redeployment of the specific investment entails considerable switching costs (Erramilli and Rao, 1993). Asset specificity can be associated with site specificity (the location in which transaction parties are involved in a specific transaction), human asset specificity (the knowledge of staff that is specific to a transaction), and physical asset specificity (the specific actions or inputs for a particular transaction) (Williamson, 1981). The specific assets in this study mainly include human assets and physical assets. Effective risk management can be achieved by good performance in project running. The most important specific asset in risk management is the organizational risk management capability (Jin and Doloi, 2008). Similarly, asset specificity in risk-related project activities is also dependent on government's capability of performing project activities.

Barriers to performing risk-related project activities can be understood as the hindrances to risk management. Table 5.2 summarizes the barriers to implementing project risk management and classifies them into lack of learning/training, divergence of strategies, information insufficiency, contextual restrictions, resource constraints, and benefit limitations. Jin and Doloi (2008) operationalized risk management capability into experience in risk management and maturity in risk management mechanism, which are also reflected in these barriers. Shortage of experienced and skilled professionals is one manifestation of resource constraints. Lack of learning/training are related to the maturity in risk management mechanism to some extent. Likewise, specific asset in this study, government's capability of performing project activities, can be considered as the experience in performing risk-related project activities and the maturity in the operation of risk-related project activities, both of which affect TCs. Buyers' transferable experience and knowledge of a good contribute to the decrease in TCs of purchase (Coggan et al., 2010). Mechanism acts as an important locus of learning (Pisano, 1994). Based on designed mechanisms, capabilities can also be developed effectively by accumulating and storing knowledge (Kale et al., 2002). A mature mechanism can effectively reduce learning costs. Therefore, the first hypothesis is proposed as follows:

H1: asset specificity hinders government performing risk-related project activities, namely that inexperience in activities and immature operation impede government's actions in risk-related project activities.

TABLE 5.2 Barriers to risk management implementation and TCs implications in the retrofitting context (Dandage et al., 2018; Hwang et al., 2014; Rasheed et al., 2015; Rostami et al., 2015; Tang et al., 2007)

Types	Barriers to risk management implementation	TC-related barriers to risk-related activities (by authors)
Lack of learning/ training	Lack of formal training to understand risk management	**Asset specificity** Maturity in the operation of risk-related project activities
	Shortage of knowledge/techniques on risk management	
	Resistance to learning something new	
Divergence of strategies	Lack of top management support	**Uncertainty** U1: Resistance of other cooperation units U2: Resistance of residential community
	Lack of consistency in risk control strategies	
	Inappropriate risk allocation	
Information insufficiency	Resistance to talking about risks	**Uncertainty** U3: Design complexity U4: Construction complexity
	Insufficient risk and project information	
Contextual restrictions	Lack of organizational culture for risk consciousness	**Uncertainty** U5: Stability of supportive policies
	Conflicts among different functions	
	Unstable organizational environment	
	Low degree of mandatory for risk management	
	Ineffective monitoring	
	Lack of government legislation	
Resource constraints	Time constraints	**Uncertainty** U6: Urgency of energy retrofitting missions U7: Rigidity of limited time and costs
	Cost and budget constraints	
	Shortage of experienced and skilled professionals	**Asset specificity** Experience in performing risk-related project activities
Benefit limitations	Lack of potential and long-term benefits	
	Low profits	

5.2.2.2 Uncertainty of project activities related to risks

Project running is exposed to environmental uncertainty. Environmental uncertainty refers to unanticipated changes in the environment where an exchange takes place (Noordewier et al., 1990). It is a multi-dimensional concept and related with both general market and specific business environments (Luo, 2007; Yang and Zhao, 2016). Energy retrofitting market in China is still immature and retrofitting projects involving various stakeholders are complicated, which creates conditions for the emergence of environmental uncertainty in project activities. In this study, environmental uncertainty represents external factors out of control of local government staff when performing the risk-related project activities, which is also the opposite of specific assets referring to internal factors from the government itself. Environmental uncertainty are identified from two sources: barriers to risk management implementation in the literature and the implementation process of residential energy retrofitting projects.

Barriers to risk management identified by previous studies (shown in Table 5.2) can provide some implications for environmental uncertainty of performing risk-related activities in residential energy retrofitting projects. Barriers resulting from divergence of strategies, information insufficiency, contextual restrictions, and resource constraints are concerned with uncertainty about market and project environment, such as policy support, resistance of other parties involved in project activities, project complexity, and time and cost constraints.

Environmental uncertainty can also be reflected on the implementation work of energy retrofitting projects. Table 5.3 highlights the work with uncertainty identified by previous studies. These tasks with uncertainty can thus reflect the presence of environmental uncertainty of government performing project activities. Combining with the Chinese retrofitting context, Table 5.3 also shows the uncertain factors behind these tasks from the perspective of market and project environment, and considers them as environmental uncertainty of performing risk-related project activities. More explanations for each environmental uncertainty are provided in Table APP.D.1 in Appendix to Chapter 5.

TABLE 5.3 Environmental uncertainty identified from the implementation process of retrofitting projects

Stage	Retrofitting work with uncertainty	Reference	Environmental uncertainty from a TCs perspective (by authors)
Regional survey and project setup	Making an agreement with homeowners for retrofitting	(de Feijter et al., 2019)	U8: Integrity of agreement provision
	Evaluation and measurement of retrofitting feasibility	(Galatioto et al., 2017)	U9: Competence of experts for safety appraisal of buildings
			U10: Detectability of building quality
Project design and budget estimation	Design company selection	(Vullo et al., 2018)	U11: Availability to qualified design companies
	Formulation of retrofitting schemes	(Shao et al., 2014)	U12: Ambiguity of energy efficiency standards
			U13: Competence of experts for drafting standards
Construction bidding and fund appropriation	Material selection	(Killip et al., 2020)	U14: Abnormality in building material market
			U15: Maturity of material technology
	Construction company selection	(Alam et al., 2019)	U16: Ambiguity of criteria for construction companies
			U17: Availability to qualified construction companies
On-site construction	Construction inspection and supervision	(Fylan et al., 2016)	U18: Detectability of construction quality
Inspection, acceptation, and use	Retrofitting evaluation for acceptance	(Liu et al., 2020)	U19: Ambiguity of acceptance criteria
	Building maintenance after retrofitting	(Wang and Xia, 2015)	U20: Availability to property management companies
			U21: Ambiguity of quality warranty responsibilities

Problems caused by environmental uncertainty are generally related to bounded rationality, information asymmetries and the danger of opportunism. Uncertainty may be mutable and reduced by improving the state of knowledge (McCann, 1998). Information collection can help the government mitigate the uncertainty of risk management. However, high TCs will restrict decision-makers' activities of information collection so that they have to act in an uncertain state (McCann, 2013). Influenced by uncertainty, contracts cannot be written completely, further leading to the raising of ex-post TCs (Williamson, 1985). As a result, the government needs to bear more enforcement and monitoring costs to offset the uncertain outcome of project activities performed in an uncertain state. In addition to information collection, environmental uncertainty gives rise to the need for processing massive information to accomplish a given goal (Galbraith, 1974). To deal with such uncertainty, partners in an exchange have to invest in specific assets to improve their capability in information processing (Huo et al., 2018). For example, investments in the training of government staff can advance their capabilities in evaluation with environmental uncertainty, but more TCs would be incurred due to the expenditure on training. This study presents the second hypothesis as follows:

H2: environmental uncertainty prevents government from performing risk-related project activities.

5.2.2.3 Frequency of project activities related to risks

The impact of transaction frequency on TCs results from the recurring of many transactions particularly in case that the good is specific to a transaction (Williamson, 1985; Williamson, 1998). Frequent transactions between the same parties are supported by a suitable process and contract and can thus lower TCs due to the ability to capitalise on standardised procedures (Williamson, 1985). The theory suggests that the entities involved in repeated transactions are similar, and standardized models and procedures can be reused in multiple transactions. In this case, as the number of transactions grows, the fixed investment in developing procedures can be spread over more transactions, thereby increasing investment benefits (McCann, 2013).

Government’s action for risk-related project activities in each project can be regarded as a transaction. Although the transaction parities (e.g., homeowners and contractors) involved in different projects are different, they are homogeneous, especially in projects located in the same area. In China, there are unified regulations on the selection of retrofitting projects and design standards in a province. Municipal government also tends to carry out these projects based on a generic and standardised process in terms of contacting with the public, partner bidding, division of department functions etc. It means that policies and standardized procedures can be formulated and developed for all retrofitting projects in one region. Effective risk management in construction projects cannot be obtained through a one-time transaction, and it takes time to develop (Jin, 2010). Therefore, areas or cities with rich experience in energy retrofitting projects are more likely to develop standardized operation procedures of the risk-related project activities to reduce TCs per unit. The third hypothesis is developed as follows:

H3: High frequency of retrofitting project implementation contributes to government performing the risk-related project activities better.

5.3 Research methodology

5.3.1 Questionnaire survey procedure and sample size

A questionnaire survey was made in Anhui province in China. Anhui Province is one of the provinces where residential energy retrofitting has been carried out relatively early in the HSCW zone. The questionnaires were distributed online in March and April 2020 to the government staff from 9 cities in Anhui Province via workgroups of social software. All the survey participants are working in the local department of Housing and Urban-rural Development and are involved in local residential energy retrofitting projects as government representatives.

There are two sections in the questionnaire. First, the respondents were asked to report the basic information including years of working experience in the government departments, the levels of education, and the experience they have in residential energy retrofitting projects, as shown in Table 5.4. In the initial stage of the development of residential energy retrofitting, retrofitting projects were only implemented in some cities in Anhui Province. As the central government attaches greater importance to building energy efficiency, residential energy retrofitting has been promoted throughout Anhui Province in the past three years, and more cities have begun to implement the renovation for old residential buildings. Still, just as the HSCW zone lags far behind the northern heating area in energy retrofitting (Jia et al., 2021), the retrofitting progress in Anhui Province also varied in different cities, leading to the difference of the questionnaire participants in the experience in residential energy retrofitting. Currently, there are still few cities that have carried out large-scale energy retrofitting, so that only a small number of survey respondents have participated in more retrofitting projects. Second, respondents were instructed to measure three kinds of variables (including government's behavioural intentions towards the risk-related project activities, asset specificity, and environmental uncertainty) (shown in Table APP.D.2 in Appendix to Chapter 5). Meanwhile, regarding the management responsibility for each risk, this study asked the questionnaire participants for their opinions. The respondents were asked which risks the government assume the primary responsibilities of management for, which risks can be allocated to other stakeholders (as the principal managers), and what roles the government play in the management of these risks.

TABLE 5.4 Basic information on survey respondents

Variables		Frequency	Percent
Years of working experience in government departments	Below 5	35	40%
	5-10	30	34%
	Above 10	23	26%
Education	Junior college or lower	18	20%
	Bachelor	62	70%
	Master or above	8	10%
Number of energy retrofitting projects they have been involved in	1-3	41	46%
	4-5	20	23%
	6-10	14	16%
	Above 10	13	15%
Total		88	100%

Finally, 118 questionnaires were completed and 88 were used for data analysis. The response rate cannot be calculated, because this questionnaire could be accessed online by all government staff located in the workgroups of the department of Housing and Urban-rural Development in each city. To ensure the quality and accuracy of the questionnaires, this survey gave a pre-selection question to control over whether respondents have experience in residential energy retrofitting. Moreover, all participants were asked to self-evaluate their knowledge on residential energy retrofitting in their own city based on a five-point scale from 1 to 5 indicating from not knowledgeable at all to very knowledgeable. Those giving the scores of less than 3 were excluded.

5.3.2 Variables identification and measurement

5.3.2.1 Behavioural intention towards the risk-related project activities

Table 5.5 presents 13 risks that need to be given a priority by managers. These risks are identified by Jia et al. (2020, 2021) based on both expert risk assessment and public risk perception through interviews and questionnaire surveys. Jia et al. (2021) chosen ten top risks (shown in Table 5.5) as the key risks in the whole process of residential energy retrofitting projects in the HSCW zone of China based on professional practitioners' assessment. Table 5 also present seven risks perceived highly homeowners that was found out by Jia et al. (2020). As with the opinions of Kasperson et al. (1988), the public has more concern on some risks that are considered insignificant relatively by professionals. However, everyone, even including experts, can be biased when making the judgement of risks (Pidgeon, 1998). The public also has something valuable to contribute, and their insights should be respected (Slovic, 1987). Incorporating and considering a wider range of knowledge, both experts and laypeople, into risk assessment helps avoid misjudgements resulting from narrow and inadequate knowledge (Bickerstaff, 2004). Therefore, this study combines expert risk assessment with homeowners' risk perception to determine risk priorities. Each risk is managed independently as an individual except for two risks of *Poor performance in cooperation* and *Opportunistic renegotiation*. These two risks are related to homeowners' attitudes towards cooperation during the on-site construction, and are thus integrated together to be analysed.

TABLE 5.5 Risks with a high priority to be mitigated in China

No.	Risks	Expert risk assessment by Jia et al. (2021)	Homeowners' risk perception by Jia et al. (2020)
R1	Lack of awareness of energy efficiency retrofitting	√	
R2	Lack of technical staff with specific expertise	√	√
R3	Lack of appropriate technical standards	√	
R4	Unqualified building materials		√
R5	Lack of construction skills	√	
R6	Moral hazard		√
R7	Poor quality of old residential buildings themselves	√	√
R8	Poor construction management	√	
R9	Poor safety management	√	√
R10	Poor performance in cooperation	√	
	Opportunistic renegotiation	√	
R11	Inadequate maintenance	√	√
R12	Difficulties in post-retrofit repair		√

The participants of questionnaire survey were first asked to assess government's behavioural intention towards these projects (see Table APP.D.2 in Appendix to Chapter 5). For example, the participants were asked directly for their opinions on "the government intends to make more efforts on persuading and encouraging homeowners to strengthen their awareness of energy retrofits". This measurement is a 5-point Likert-type scale from one (strongly disagree) to five (strongly agree).

5.3.2.2 Asset specificity

The degree of asset specificity is measured by the survey participants in two aspects of the ***experience in performing risk-related project activities*** (AS1) and the ***maturity in the operation of risk-related project activities*** (AS2) (see Table APP.D.2 in Appendix to Chapter 5). Participants were asked to rate, for instance, “experience in selecting the qualified design company” and “the maturity in the operation of selecting the qualified design company” for *Lack of technical staff with specific expertise* (R2). All the items were measured on a five-point scale from 1 to 5 indicating the degree from very low to very high.

5.3.2.3 Environmental uncertainty

As shown in Table 5.2 and Table 5.3, 21 factors were identified to constitute environmental uncertainty in project activities of residential energy retrofitting. Participants in the questionnaire survey were invited to evaluate the degree of uncertainty by using a five-point scale from 1 to 5 (see Table APP.D.2 in Appendix to Chapter 5). For example, participates were asked to judge the *Resistance of other cooperation units* (U1), and 1 and 5 indicate “supportive” and “resistant” respectively; for *Design complexity* (U3), 1 and 5 indicate “simple” and “complex” respectively. The higher the score given is, the greater the uncertainty is.

5.3.2.4 Frequency

Frequency of retrofitting transaction is measured in the number of the completed residential energy retrofitting projects in each city in 2019. Anhui province has started to implement energy retrofitting of residential buildings in more cities since 2018. A wider coverage and a significant increase in the number of retrofitting projects were achieved in 2019. All the projects completed in 2019 were implemented in the same and latest policy and market environment. This study counted the number of retrofitting projects in 2019 in each city separately and associated this data with the survey participants from different cities.

5.3.3 **Data analysis**

5.3.3.1 Exploratory factor analysis (EFA)

EFA is employed by using SPSS software to statistically identify the underlying relationships between the variables in the group of uncertainty, aiming to simply these variables by identifying a small number of principle components. EFA assumes that the variance in the observed variables results from the presence of some common factors and variables sharing common factors are strongly correlated. This method has two main purposes: identifying the minimum numbers of latent factors that can contain the maximum amounts of information from the original observed variables and exploring how the original variables are configured in latent factors (Jhonson and Wichern, 2007). This study adopts EFA to statistically extract common factors from 21 uncertainties and to configure these uncertainties in different common factors. EFA is the basis for ANN further adopted in this study. The fewest input variables are required to describe the variance of the output variable in order to minimize the degree of redundancy (May et al., 2011). The result of EFA is used to determine the input variables of the ANN model.

Sample size is a main issue to check the reliability of EFA because small sample sizes lead to unstable correlation coefficients (Field et al., 2012). A range of between 5 to 10 participants per variable for EFA were recommended by Kass and Tinsley (1979). The final ratio of cases to variables used for EFA is 5.9, that is within the required range.

Bartlett's test of sphericity (Bartlett, 1937) and the Kaiser-Meyer-Olkin (KMO) measure of sampling adequacy (Kaiser, 1970, 1974) are used to test the suitability of the data for factor analysis. Bartlett's test of sphericity tests the whole correlation matrix by identifying the correlations between variables. A statistically significant Bartlett's test of sphericity ($p < 0.05$) is considered appropriate for factor analysis. The KMO indicates the proportion of variance in the original variables that might result from underlying factors. A value of 0.6 was suggested by (Tabachnick et al., 2007) as the minimum value of the KMO to continue with factor analysis.

5.3.3.2 Artificial neural network (ANN)

An ANN model is adopted by using SPSS software to validate the influence of TC-related factors on government's performance in the risk-related project activities as well as to rank these factors. ANN is a powerful tool for predictive data mining applications due to its characteristics of high-speed information processing, mapping, fault tolerance, adaptiveness, generalization, and robustness (Elsheikh et al., 2019). ANN can be used to model and solve complex and nonlinear multivariate problems.

The Multilayer Perceptron (MLP) algorithm is applied to the development of the ANN model in this study. MLP is a common method to solving regression-type problems. There are three layers in a MLP network (presented in Figure 5.1), including input layer, hidden layer and output layer. Values of inputs are summed up based on the assigned weights and a bias is added, forming transfer function and activation function and further determining the value of the output. The number of neurons in the input and output layer corresponds to the amount of input and output variables, respectively. The procedure of automatic architecture was set in SPSS neural network in this study to reach the best network structure, and thus, the best number of neurons in the hidden layer was founded out through the automatic selection procedure.

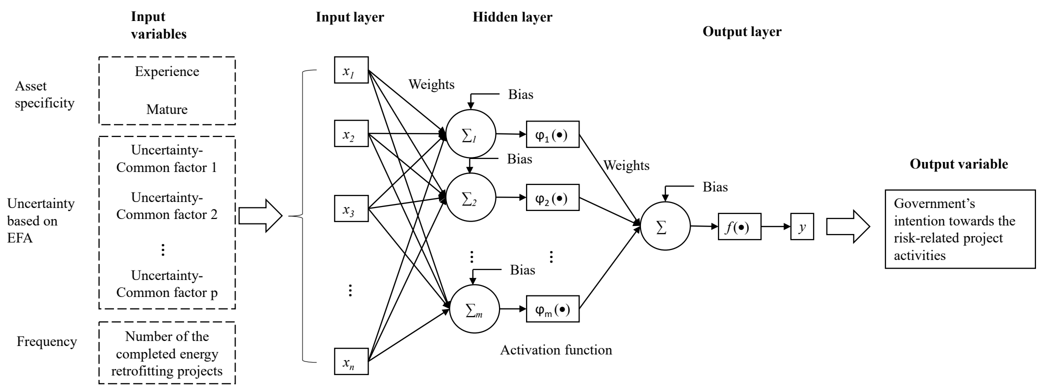

FIG. 5.1 Structure of the three-layer MLP neural network

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This study established two neural networks for each risk, involving one hidden layer and two hidden layers respectively. A standardized method is viewed as rescaling method of scale dependent variables to improve network training. The original dataset was divided into two portions of training and testing data. Overall, 88 original datasets comprise the samples from 9 cities. At least 20% of samples in each city were selected randomly to constitute the 'testing dataset', and the remaining 80% are viewed as the 'training dataset'. All models were trained and tested using the same datasets. Given the small size of samples, batch was selected as the training type to process the records. A Scaled Conjugate Gradient, as the optimization algorithm, was used to estimate the synaptic weights.

ANN is initialised with random weights at the start of each training, leading to different results for the same data every time. To gain a good-fit model, each neural network was trained for 60 times. The performance of each model was evaluated using Root Mean Square Error (RMSE) of training and testing datasets. RMSE is the standard deviation of the residuals (prediction errors) to measure the difference between the predicated values and the observed values. There are two criteria of selecting the best fit model for each neural network: the values of RMSE of training and testing are similar and small. RMSE is calculated as follows:

$$\mathrm{RMSE}_{training} = \sqrt{\frac{\sum_{i=1}^{n}(\hat{y}_i - y_i)^2}{n}} \quad (1)$$

$$\mathrm{RMSE}_{testing} = \sqrt{\frac{\sum_{j=1}^{m}(\hat{y}_j - y_j)^2}{m}} \quad (2)$$

where $\hat{y}_i / \hat{y}_j$ and y_i / y_j are the *i*th/*j*th predicted and actual outputs in the training/testing dataset, respectively; n/m is the number of training/testing cases.

Two best fit models were selected for the neural networks of each risk, representing the ANN model with one hidden layer and the model with two hidden layers. The final model for each risk was further selected from these two models. In addition to RMSE, two other performance indexes were used to compare those models with similar RMSE. The Mean Absolute Percent Error (MAPE) is an indicator to measure the magnitude of the errors of predictions. The coefficient of determination (R^2) is also a goodness-of-fit measure of how close the data are to the model and indicates the percentage of the variance that is interpreted by the model.

They are defined as follows:

$$\mathrm{MAPE}_{training} = \frac{1}{n}\left(\sum_{i=1}^{n} \frac{|y_i - \hat{y}_i|}{y_i}\right) \times 100\% \tag{3}$$

$$\mathrm{MAPE}_{testing} = \frac{1}{m}\left(\sum_{j=1}^{m} \frac{|y_j - \hat{y}_j|}{y_j}\right) \times 100\% \tag{4}$$

$$\mathrm{R}^2{}_{training} = 1 - \frac{\sum_{i=1}^{n}(y_i - \hat{y}_i)^2}{\sum_{i=1}^{n}(y_i - \bar{y}_i)^2} \tag{5}$$

$$\mathrm{R}^2{}_{testing} = 1 - \frac{\sum_{j=1}^{m}(y_j - \hat{y}_j)^2}{\sum_{j=1}^{m}(y_j - \bar{y}_j)^2} \tag{6}$$

where $\hat{y}_i / \hat{y}_j$ and y_i / y_j are the ith/jth predicted and actual outputs in the training/testing dataset, respectively; $\bar{y}_i / \bar{y}_j$ is the mean of the actual values in the training/testing dataset; n/m is the number of training/testing cases.

5.4 Results

5.4.1 Uncertainty classification based on EFA

According to the mean values of 21 uncertainty indicators (shown in Table APP.D.3 in Appendix to Chapter 5), this study first deleted 6 uncertainties with the mean of less than 3, including U1, U2, U5, U9, U13, and U21.

The results of the KMO and Bartlett's tests for 15 uncertainties are shown in Table 5.6. The KMO value is 0.835, suggesting that the variables are interrelated. Bartlett's test of sphericity test shows that the overall significance of the correlation matrix is 0.000, which means that the data matrix has sufficient correlation for the purpose of factor analysis. Therefore, factor analysis is considered to be appropriate for these variables.

TABLE 5.6 KMO and Bartlett's Test

Kaiser-Meyer-Olkin Adequacy	Measure of Sampling	0,835
Bartlett's Test of Sphericity	Approx. Chi-Square	689,242
	df	105
	Sig.	0,000

Table 5.7 presents the final extracted factors, the uncertainty indicators of each factor, and the corresponding statistical data. After the rotation, four factors are extracted and explain 68.32% of the variance in the data with eigenvalues more than 1. The communalities for retained variables range from 0.55 to 0.83 indicating that these variables can be fairly well explained by the extracted factors.

TABLE 5.7 Results of exploratory factor analysis

Components/Variables	Factor loading	Eigen value	Variance explained %	Communalities
Retrofit complexity and quality (FAC1)		3,35	22,32	
U3 Design complexity	0,83			0,83
U4 Construction complexity	0,80			0,76
U18 Detectability of construction quality	0,76			0,76
U20 Availability to property management companies	0,70			0,61
U10 Detectability of building quality	0,69			0,69
Retrofitting market maturity (FAC2)		3,12	20,80	
U14 Abnormality in building material market	0,85			0,76
U15 Maturity of material technology	0,80			0,71
U17 Availability to qualified construction companies	0,66			0,62
U16 Ambiguity of criteria for construction companies	0,59			0,55
U19 Ambiguity of acceptance criteria	0,56			0,62
Costs and time restriction (FAC3)		2,30	15,35	
U7 Rigidity of limited time and costs	0,80			0,73
U6 Urgency of energy retrofitting missions	0,67			0,55
U8 Integrity of agreement provision	0,62			0,64
Design basis (FAC4)		1,48	9,85	
U12 Ambiguity of energy efficiency standards	0,79			0,73
U11 Availability to qualified design companies	0,75			0,70

The results of EFA show that *Design complexity* (U3), *Construction complexity* (U4), *Detectability of building quality* (U10), *Detectability of construction quality* (U18), and *Availability to property management companies* (U20) are given high factor loadings on ***Retrofit complexity and quality*** (FAC1). Other variables U3, U4, U10, and U18 are related to the complexity of the retrofitting implementation and influence retrofitting quality. The undetectability of quality increases the retrofitting complexity, but project complexity also leads some important quality problems to be ignored. The high factor loading of U20 on FAC1 may also be influenced by quality problems. The poor quality of old residential buildings is also an important barrier to the entry of property management companies. Quality problems omitted beforehand would become the responsibilities of property management companies so that they have to bear the great losses, which also leads property management companies to be reluctant to take over the old residential communities.

Abnormality in building material market (U14), *Maturity of material technology* (U15), *Ambiguity of criteria for construction companies* (U16), *Availability to qualified construction companies* (U17), and *Ambiguity of acceptance criteria* (U19) are classified as ***Retrofitting market maturity*** (FAC2). These uncertainties all are related to the maturity of the retrofitting market, involving energy-saving materials and retrofitting construction companies. Moreover, the acceptance standard of retrofitting projects also goes into the same category as the technical standards in the energy retrofitting market and is an important criterion for judging the completion of retrofitting tasks.

Urgency of energy retrofitting missions (U6), *Rigidity of limited time and costs* (U7), and *Integrity of agreement provision* (U8) are heavily dependent on ***Costs and time restriction*** (FAC3). Both U6 and U7 are related to the time limit of the retrofitting project. Meanwhile, U8 may also be affected by the limited construction period, resulting in insufficient time to negotiate with homeowners and propose a complete retrofitting protocol.

Availability to qualified design companies (U11) and *Ambiguity of energy efficiency standards* (U12) are grouped into ***Design basis*** (FAC4). These two uncertain factors are associated with energy-saving design, including design standards and designers.

5.4.2 Effects of TC-related factors based on ANN

The values of RMSE, MAPE, and R^2 of 24 models for 12 risks are shown in Table APP.D.4 in Appendix to Chapter 5. There are two models for each risk, involving one hidden layer and two hidden layers. For each risk, the values of RMSE, MAPE, and R^2 were compared between two models to select the one of the best fit. The final model for each risk is also highlighted in Table APP.D.4.

Table 5.8 presents the normalized importance of TC-related variables in 12 final models. The larger the percentage is, the more important the factor is to the participation in project activities. The top three factors for each risk are highlighted in Table 5.8. To further understand the relationships between these factors and government performance in project activities, this study visualized the functions fitted by neural network models. One variable is varied and the others keep constant during the visualization. The arithmetic means of variables are used as the constants. The neural network function was applied to the dataset to produce a predicted value for each value of the independent variables being visualized. Taking examples of R2 and R3 that are mainly affected by the same three TC-related factors, Figures 5.2 plots the relationships between the top three independent variables (Maturity, FAC3, and FAC1) and the predicted value of the dependent variable. More plots are shown in Figure APP.D in Appendix to Chapter 5.

TABLE 5.8 Normalized importance of independent variables in models

	Asset specificity		Uncertainty				Frequency
	Experience	Maturity	FAC1	FAC2	FAC3	FAC4	
R1	41,9%	**100,0%**	22,3%	46,7%	**57,2%**	**51,5%**	41,7%
R2	40,8%	**100,0%**	**41,0%**	34,5%	**48,1%**	36,5%	12,4%
R3	15,3%	**100,0%**	**28,4%**	20,0%	**37,1%**	20,1%	12,9%
R4	17,3%	**100,0%**	18,8%	**32,4%**	**38,4%**	26,3%	26,5%
R5	**100,0%**	**93,1%**	**71,2%**	22,6%	41,1%	32,5%	20,8%
R6	**45,0%**	**100,0%**	**34,1%**	16,0%	27,8%	10,6%	21,1%
R7	**80,9%**	**100,0%**	**55,5%**	17,0%	8,0%	18,7%	13,0%
R8	**76,7%**	**100,0%**	**80,7%**	46,2%	66,9%	2,9%	23,0%
R9	26,8%	**100,0%**	**33,6%**	**46,8%**	13,4%	16,7%	12,4%
R10	**100,0%**	**62,2%**	5,6%	20,0%	**41,2%**	12,9%	36,1%
R11	**100,0%**	**87,0%**	**41,9%**	15,6%	14,8%	13,6%	11,3%
R12	12,1%	**100,0%**	**49,1%**	**49,9%**	32,7%	19,2%	4,4%

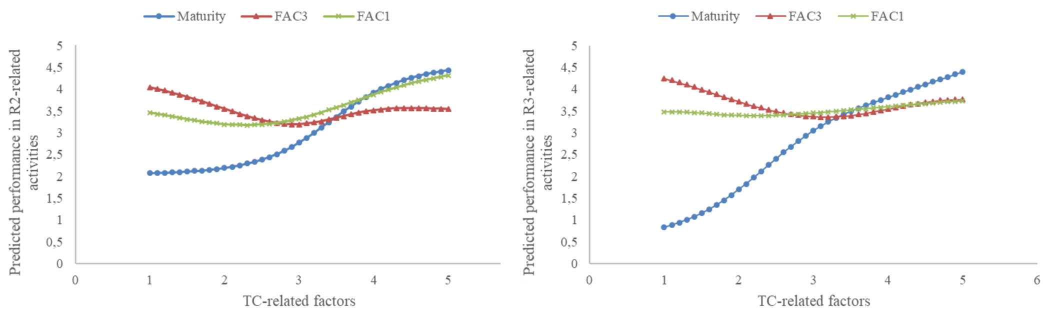

FIG. 5.2 Effects of three top TC-related factors on performance in project activities related to R2 and R3

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5.4.2.1 Effects of asset specificity

The analysis results support hypothesis H1. **Maturity** in the operation is the most important factor affecting government performance in project activities. **Rich experience** also contributes to the participation in risk-related project activities, but the difference is that **experience** does not improve government performance in project activities related to all risks as much as **maturity** does. In particular, the impacts of **experience** on performing the project activities related to *Lack of appropriate technical standards* (R3), *Unqualified building materials* (R4), and *Difficulties in post-retrofit repair* (R12) are very small.

5.4.2.2 Effects of environmental uncertainty

The uncertainty on *Retrofit complexity and quality* (FAC1) is directly proportional to the performance in risk-related project activities, which is contrary to hypothesis H2. In H2, TCs caused by project complexity and quality undetectability would hinder the government to perform project activities, but this empirical study shows that these uncertainties are important drivers for activity execution. The exception is that, the role of FAC1 in performing the activities related to *homeowners' cooperation* (R10) is very small, accounting for only 5.6% of the most influential factor (*Experience*).

Contrary to FAC1, the remaining factors FAC2, FAC3 and FAC4 impede the execution of risk-related project activities, a finding which is consistent with H2. Among these three factors, *Costs and time restriction* (FAC3) is the most important obstacle. The results of this study show that FAC3 is one of the three main factors affecting government performance in project activities related to *Lack of awareness of energy efficiency retrofitting* (R1), *Lack of technical staff with specific expertise* (R2), *Lack of appropriate technical standards* (R3), *Unqualified building materials* (R4), and *Homeowners' cooperation* (R10).

Uncertainty regarding *retrofitting market maturity* (FAC2) is one of the main barriers to performing the project activities related to *unqualified material quality* (R4), *poor safety management* (R9), and *difficulties in post-retrofit repairing* (R12).

The influence of *Design basis* (FAC4) is the least among all uncertainties. The importance of FAC4 is only reflected in project activities regarding *Lack of awareness of energy efficiency retrofitting* (R1).

5.4.2.3 Effects of frequency

The impacts of frequency on activity execution are the smallest among all TC-related factors, which cannot support H3. It may be due to the fact that there is little difference in the scale of the completed retrofitting projects among more than half of the cities in the empirical analysis, which leads the participation in risks management to be insensitive to frequency.

5.4.3 The allocation of risk management responsibility

According to respondents' views on risk allocation, more than 50% of the participants believed that the government should assume the primary responsibility for addressing the risks about homeowners' awareness and cooperation (R1 and R10), expertise of technical staff (R2), technical standards (R3), and building quality (R7). Other project parties especially contractors need to be in charge of other risks, and the government is responsible for supervision and guidance.

5.5 Discussion and policy recommendations

Given the different roles of the government in mitigating different risks, this study discusses government strategies for risk mitigation in two ways (shown in Figure 5.3). It first explains the importance of experience in performing risk-related activities, maturity in the operation of these activities, and costs and time restriction acting as the barriers to government's behaviours. These barriers are also the bases for developing government strategies to mitigate the risks regarding homeowners' awareness and cooperation, expertise of technical staff, technical standards, and building quality. In addition, mature retrofitting market is considered as the foundation of government acting as the supervisor and guide in terms of the mitigation of other risks.

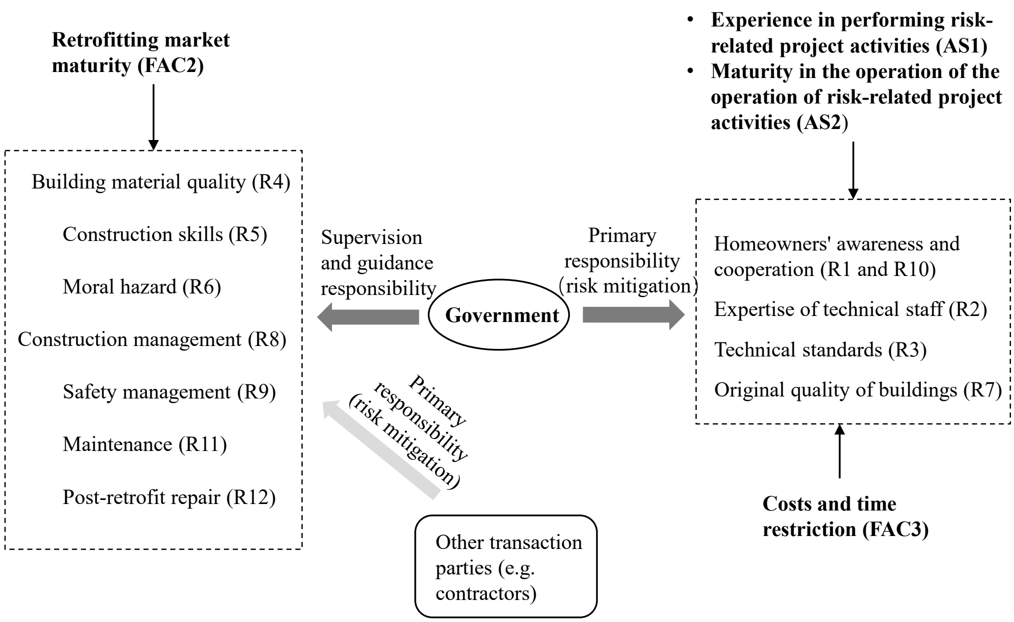

FIG. 5.3 Government's risk management responsibilities and key barriers to performing risk-related activities (by authors)

5.5.1 Dominant role of government capability of activity execution in risk mitigation

Government's capability involving the experience in performing risk-related project activities and the maturity in the operation of risk-related project activities is the key factor affecting government performance in risk-related project activities. Still, experience is confirmed to have little effect on activity execution regarding risks about technical standards, building materials, and post-retrofit repair. At present, China has issued a series of policies and standards for promoting building energy efficiency, but the regulation-based policies are mainly related to new buildings (Li and Shui, 2015). Even for building retrofitting, the government's experience in formulating the relevant regulations and standards is mostly concentrated on residential buildings in China's northern heating regions and public buildings (Li and Shui, 2015; Liu et al., 2020). In such cases, the previous experience is difficult to be used for developing the technical standards of housing retrofitting in the HSCW zone. For the risks regarding building materials and post-retrofit repair, government's previous experience is indirect. In the completed projects, the local government is not directly involved in material procurement, testing, maintenance and, repair. These are mainly the responsibility of the construction companies, which may also be the reason for the low influence of experience on government's performance in the relevant project activities.

By contrast, the impacts of maturity in activity operation are more widespread. A low degree of maturity in the operation means that, the government is likely to fail to take effective actions to perform the risk-related project activities under the existing framework of operation. It does not only reduce the government's confidence in these activities, but also leads to more TCs incurred by extra tasks to deal with the fallout from ineffective actions. A mature mechanism contributes to the accumulation of experience (Kale et al., 2002). The optimization of the operation mechanism of the relevant activities can be used to alleviate barriers to activity execution of the government. The participants in the survey agree that the government should assume the primary responsibility of reducing the risks about homeowners' awareness and cooperation, expertise of technical staff, technical standards, and building quality. Correspondingly, the operation of project activities related to these risks should also be optimized to improve government performance in the relevant activities.

5.5.1.1 Information popularization

The project activities regarding motivating homeowners' awareness and cooperation can be operated via information popularization. Popularizing building retrofitting information contributes to the enhancement of homeowners' willingness to energy retrofitting (Liu et al., 2020). Information measures have been implemented to raise public awareness of energy efficiency in the EU (Rivas et al., 2016). Internet, TV and radio have been recognized as the effective information tools by European countries (e.g., Demark, France and Italy). The Netherlands has developed a specific website to provide information on incentives, grants and subsidies for homeowners who want to invest in energy efficiency. In terms of face-to-face communication, France established hundreds of retrofitting information service points nationwide to develop a local network for energy retrofitting. Likewise, China has highly-developed mass media and can use it to provide the long-term retrofitting information popularization, such as periodical public announcements via TV and radio and developing websites specific for retrofitting activities, projects, and measures. Face-to-face interaction can be viewed as a more targeted measure to provide information for the residential communities planned to be renovated. For instance, the housing department of the district government appoints the department officers or industry professionals to provide an on-site information service with the assistance of neighbourhood committees or sub-district offices, and audio-visual presentations can even be considered.

5.5.1.2 Establishment of energy service databases

The operation of project activities involving the risk of expertise of technical staff is dependent on how to select the design company. The architectural design company is in charge of the selection of energy-saving technology and the formulation of technical schemes in residential energy retrofitting projects in China. The selection of design teams for renovation projects funded by the local government is characterised as two ways, namely direct appointment and bidding. The field survey shows that, the design of the pilot project a few years ago was mostly undertaken by the local municipal institute of architectural design. In the past two years, the bidding system has been used more commonly in retrofitting projects with the expansion of the renovation scale. By contrast, some European countries (e.g., Germany and Spain) are committed to establishing databases related to an energy-saving service, involving companies and experts. In particular, the list of energy efficiency experts created by Germany is recognized throughout Europe. In the Chinese context, the establishment of databases can be considered as a supplementary measure to the bidding system. Databases are used to limit the scope of design bidding to the lists containing qualified design companies to ensure that all bidders have capacities of designing energy retrofitting schemes of old residential buildings.

5.5.1.3 Exchanges of technology experience

Optimizing the operation of formulating technical standards can be achieved through exchanges of technology experience. The latest industry standard for energy-saving renovation technology of residential buildings was issued in 2013, and it was compiled by the China Academy of Building Research and some provincial design and building research institutes. On the basis of the national technical specification, each province formulated provincial-level technical standards for the local energy retrofitting projects according to their own economic and climate conditions. The authors' personal communications with the government departments in charge of energy retrofitting in the survey areas revealed that, standardized technical specifications are difficult to be put into practice especially in the HSCW zone, and technical solutions are mostly developed dependent on the practical experience in the local retrofitting projects. In this respect, Italy and France have actively created regional energy networks to promote the exchange of energy-saving strategies and technology sharing by linking dozens of organizations. Such technical exchanges can also be conducive to the accumulation of experience in retrofitting technology in China. It is suggested to establish an exchange platform for provinces in the same climate region to share technical experience and develop more mature and appropriate energy retrofitting technical specifications for old residential buildings.

5.5.1.4 Perfecting building diagnosis before retrofitting

Perfecting building diagnosis contributes to the improvement of testing the building quality before retrofitting. The technical specification for energy retrofitting of residential buildings issued in 2013 made the provisions for energy-saving diagnosis. For buildings in the HSCW zone, the diagnosis includes energy consumption for heating and air-conditioning, indoor thermal environment, and building envelope structure. The diagnosis of the envelope structure does not only involve energy consumption indicators (e.g., thermal performance and heat transfer coefficient), but also can be used to check the quality of the building itself, such as cracks, leakage, damage, structural structure, window types, and floor thickness. However, few projects operate energy-saving diagnoses completely in accordance with specifications in practice. Most of the diagnosis work was undertaken by the design company of the retrofitting project as part of the site survey before design. Structural experts were also invited to diagnose the quality of the buildings in some projects. Currently, some retrofitting projects in the northern heating region have regarded energy-saving diagnosis as an independent project in which testing institutions for energy-saving diagnosis were selected through public bidding. This approach can systematically diagnose the building and issue a more complete diagnosis report to reduce the project risk posed by poor original building quality, an approach which should be applied widely to more projects.

5.5.2 Varying roles of environmental uncertainty in different risks

5.5.2.1 Quality objective and awareness of responsibility acting as impetuses of risk-related activities

The positive role of environmental uncertainty from retrofit complexity and quality in activity execution stems from the direct impact of these uncertainties on project quality. Quality plays a key role in three objectives (time, cost, and quality) of assessing the success of a project (Basu, 2014). Environmental uncertainty related to project quality is one of the hidden dangers hindering project success. Under a high degree of such uncertainty, the government, as the investor of retrofitting projects, can obtain more benefits by improving their performance in project activities to mitigate the influence of these uncertainties. Similarly, Huo et al. (2018) confirmed that more specific assets were required to address environmental uncertainties but this investment could also reduce other costs. Likewise, the improvement of homeowners' awareness and cooperation seems to fail to reduce the impacts of this uncertainty. The enhancement of homeowners' cooperation is involved in cognitive issues and have little impact on retrofitting quality, which also explains the insignificant role of this environmental uncertainty in government strengthening homeowners' cooperation.

The complexity of design and construction and the detectability of building quality are the inherent problems of the project itself, which are related to the project selection in the early stage. Project selection is mainly the responsibility of the government, and the awareness of their own responsibilities encourages them to perform the risk-related activities better in order to reduce the impacts of uncertainty caused by project selection. This is consistent with Jia et al. (2020), in that the sense of duty and responsibility can promote measures of risk mitigation.

5.5.2.2 Selective execution of risk-related activities under the constraints of costs and time

The lack of flexibility in time and costs directly limits the government's expenditure on some extra work, thereby hindering their activity execution. The performance in activities involved in issues of the market context, such as persuading the public to raise their awareness and formulating the appropriate technical standards, cannot be improved in a short period of time. The long-term measures (e.g., education) are necessary for the improvement of public awareness (Younis, 2015). Meanwhile, the establishment of technical standards are also time-consuming, from the preliminary stage to the rechecking stage (SBQTS, 1997). Time and cost constraints also amplify the effects of other barriers. The government's perception about three risks of designer's ability, technical standard applicability, and material quality is low compared to their perception on most other risks, while people tend to take actions for reducing those risks with high levels of perception (Jia et al., 2020). Still, in terms of the risks perceived highly, people's behaviours can also be limited by economic conditions (Wachinger et al., 2013). Similarly, time and cost constraints further prevent the government from reducing the occurrence probability of those risks with low degree of perception by improving their performance in the relevant project activities.

Limited by the specific financial allocations and the number of tasks for energy retrofitting projects each year, the government cannot devote more to pursuing the perfect performance in all activities of retrofitting projects. This is also one of the characteristics of the local government-led model. The local government seems to focus more on whether they can achieve the political goal of the number of renovated buildings, but to be less concerned about the retrofitting technology and energy-saving effect (Liu et al., 2015). To complete the required number of retrofitting within a finite time, the local government is more inclined to adopt more traditional energy-saving technologies to ensure that the limited financial budget can afford more retrofitting projects.

1 Developing financing diversification

Financing diversification is an approach to relieving cost constraints. It requires to explore other financing channels for retrofitting projects instead of relying solely on financial allocations from governments at all levels. In fact, the government has been encouraged to seek more financial support for renovation projects (Li and Shui, 2015; Liu et al., 2020), but there are still few achievements to show for it. In the Netherlands, renovation investors are provided with tax incentives and are also eligible for funding at lower interest rates. Similarly, the Chinese government can also consider to develop more incentives to increase owners' willingness of investing in energy retrofitting as well as encourage financial institutions to provide preferential loan services for energy retrofitting projects.

2 Promoting post-evaluation of retrofitting projects

The government should not ignore the purpose of the retrofitting itself for the urgency of the retrofitting task. The number of the completed projects cannot be viewed as the only criterion for judging the completion of retrofitting targets. Although China has issued the Assessment Standard for Green Retrofitting of Existing Buildings, the voluntary nature of this certification scheme makes it rarely applied in practice (Liu et al., 2020). The government should not blindly pursue the quantity when formulating energy retrofitting plans. Instead, more attention needs to be paid to the energy-saving effects that can be achieved in order to promote the application of the retrofit evaluation standard in practice.

5.5.2.3 Mature retrofitting market contributing to activity execution involving various parties

A mature retrofitting market is the prerequisite for better performing the project activities related to construction risks better. The transformation of building material industry in China requires the mutual involvement of government, building materials companies, building developers and building consumers (Yin et al., 2019). It is difficult for the government to quickly alleviate the uncertain factors related to the market. Under the joint constraints of cost and time and its own risk management capabilities, the government may also be reluctant to spend limited resources on the work that is hard to be achieved. In addition, retrofitting market maturity contains the uncertainty about construction companies in the market context. If intending to strengthen safety management that the construction company is in charge of, the government needs to trace the origins to reduce the uncertainty in the construction market, namely ensuring construction safety through capable construction companies. Nevertheless, more TCs (e.g., training costs and search costs) would be incurred during this process, thereby reducing the economic efficiency of such activities. Similarly, the construction company is involved in government's activity of formulating and perfecting the schemes of post-retrofit repair. The construction company needs to undertake the obligation of repairing within the warranty period after the retrofitting. For this reason, the improvement of the maturity of the retrofitting market is also necessary for achieving good performance in this activity. This involves not only construction companies that undertake repair tasks, but also energy-saving materials and equipment. It also means that more stakeholders are involved in this activity and more TCs would be incurred by their exchanges.

The government has the responsibility to supervise and guide risk management related to materials and construction. Still, the uncertainty on the retrofitting market involving energy-saving materials and construction companies limits government's behaviours in risk-related project activities, so that the probability of risk occurrence cannot be reduced through government good performance in these activities. The optimization of monitoring the construction market is necessary for government's supervision on public investment projects in China (Wu et al., 2012), which means that the implementation of government's supervisory responsibility also need to start from the market. In addition to a series of regulations mentioned earlier to strengthen the supervision during the construction, it is necessary to improve the regulations of the retrofitting market.

Encouraging material and personnel certification

Certification regime as a new form of governance has emerged to regulate the market by creating incentives for particular kinds of behaviour (Haufler, 2003). This kind of regulation reduces the frequency of market failure by relieving information asymmetry (Vertinsky and Zhou, 2000). In Germany, a certification system has been built specific for qualified energy service providers (e.g., energy consultants and building workers). Belgium has also established a database containing building energy-saving materials and encourages to provide quantitative verified information on these materials. Certification regimes for building materials and construction companies servicing energy retrofitting can also be encouraged in China in order to promote the establishment of the market that is able to offer qualified services for retrofitting projects.

5.6 Conclusions

Risks exist in the whole process of residential energy retrofitting projects in the HSCW zone of China. Transaction costs (TCs) incurred by the risk-related project activities cause the increase in the TCs in the retrofitting transaction, impeding the smooth implementation of retrofitting projects. The government is the key to the promotion of successful residential energy retrofitting, and so plays an important role in risk management of retrofitting projects in China. The high level of TCs is actually an obstacle to the government running projects effectively. The government's behaviours in the risk-related project activities are restricted by TCs, which, in turn, hinder the reduction of risk probability. To promote the smooth implementation of residential energy retrofitting projects, and by using a TCs focus, this study explored the risk-related barriers to government running projects, and thus provides the policy recommendations for barrier alleviation and measures for risk mitigation.

The effects of three TC-related factors (asset specificity, uncertainty, and frequency) on government's behavioural intentions towards the project activities related to each risk were modelled based on Exploratory Factor Analysis (EFA) and Artificial Neural Network (ANN) as described in Section 5.4 (See Table 5.7) (See also Figure 5.3 in Section 5.5). The analysis leading to this model confirms that the two influences of ***asset specificity*** and ***uncertainty*** are more prominent. ***Immaturity in the operation of project activities*** is the most important barrier to smooth running of projects. In terms of barriers related to environmental uncertainty, those relating to ***costs and time restriction*** and ***immature retrofitting market*** should be addressed first. The factor of ***retrofit complexity and quality*** is the most influential uncertainty, but this uncertainty is a motivator of activity execution of the government rather than an obstacle.

Taking the survey respondents' views on risk allocation together, this study reveals that the government plays different roles in the management of different risks. The findings of this study suggest several measures to improve the operation of preventive actions and relieve the restrictions of costs and time. Attention to these will reduce the probability of the risks regarding homeowners' awareness and cooperation, expertise of technical staff, technical standards, and building quality via government good performance in project activities. This can be achieved by government (or appropriate agencies), in advance of retrofitting projects, disseminating information, establishing energy service databases, exchanging technology experience, promoting building diagnosis, developing financing diversification, and promoting post-evaluation of retrofitting projects. The mitigation of other risks related to on-site construction and post-retrofitting usage, requires the supervision and guidance of the government, which is also concerned with the maturity of the retrofitting market and can be promoted by encouraging certification of both material and personnel standards.

By providing a TCs lens for understanding the influence of risks on government running projects and exploring the key factors of risk mitigation, this research contributes to the body of knowledge in the fields of barriers to project implementation and risk mitigation policies. However, this study has limitations, which can and should be addressed in future research. First, the data samples are limited because the empirical study was made in only one province in the HSCW zone of China. Future research studies can conduct the field surveys for further retrofitting projects in other provinces, to further analyse government's roles in retrofitting project running and RM. Second, risk mitigation recommendations were developed from the perspective of the government, but other project parties (e.g., construction companies and homeowners) also need to be involved in the management of some risks. Future studies can explore how to mitigate risks through greater knowledge of the behaviours of other key project participants.

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6 Conclusions

This chapter concludes the main research findings, provides policy implications, and presents limitations and recommendations for future research.

6.1 Highlights in summary

Since 2006 in China, energy retrofitting of residential buildings has been highlighted as an important approach to reducing energy consumption and carbon emissions. In turn, this addresses the issue of global warming and climate change. As one of the key climatic regions having great energy-saving potential through retrofitting, key stakeholders, especially authorities in the HSCW zone of China, need to make more effort on residential energy retrofitting. However, homeowner resistance hinders the promotion of such retrofitting. Homeowners are generally unwilling to make significant changes to their homes (e.g., the renovation of the building envelope), even if persuaded that energy retrofitting is conducive to improving building quality and their living quality (Baldwin et al., 2018). This resistance can be attributed to poor project execution/performance (e.g., cost overruns, poor quality, and project delays) that would damage their interests. Risk is an important factor resulting in these deviations of project objectives (Zou et al., 2007). Indeed, residential energy retrofitting in China is exposed to various risks due to uncertainties about finance, technology, coordination, etc. (Bao et al., 2012; Fylan et al., 2016; Liu et al., 2015; Lv and Wu, 2009). These risks are important barriers to the smooth implementation of residential energy retrofitting projects and impede the achievement of project objectives. Therefore, this thesis aims to better understand and mitigate risks in residential energy retrofitting in the HSCW zone of China. In this respect, this thesis explores the strategies for risk mitigation based on risk identification and risk assessment to accelerate the process of residential energy retrofitting in the HSCW zone of China.

The main research question of this thesis at the outset has been:

What are the risks hindering the implementation of residential energy retrofitting projects in the HSCW zone of China, and what strategies can mitigate these risks?

This question was broken down into four key questions that are answered in Chapters 2, 3, 4, and 5, respectively:

1. **What are the key risks hindering the implementation of residential energy retrofitting projects in the HSCW zone of China from the perspective of objective risk assessment?**
2. **What are the important risks perceived subjectively by different stakeholders in residential energy retrofitting projects in the HSCW zone of China?**
3. **What retrofitting information contributes to the improvement of homeowners' cooperation in residential building energy retrofits in the HSCW zone of China?**
4. **What are the strategies for mitigating risks of the government-led energy retrofitting projects in the HSCW zone of China?**

Several specific sub-questions are involved in each key research question, respectively. Table 6.1 presents the responses to each sub-question.

TABLE 6.1 Summary of Answers to the Research Questions

	Key question	Sub-question for each key question	Answers to the research questions
Chapter 2	What are the key risks hindering the implementation of residential energy retrofitting projects in the HSCW zone of China from the perspective of objective risk assessment?	What are the major tasks and stakeholders involved in the whole process of retrofitting projects in practice?	· Four main stakeholder groups are identified, including government, homeowners, designers, and contractors. · The five main project stages are regional survey and project setup, design and budget estimation, construction bidding and fund appropriation, on-site construction, inspection, acceptance, and use.
		What are the risks that should be given a higher priority based on risk probability and impact?	Twenty-one risks are identified, and those ranked in the top ten are viewed as the key risks. The ten key risks are related to homeowners' participation and cooperation, the competence of designers and contactors, construction management, safety management, maintenance, etc.
		What are the focuses of mitigating key risks from the perspectives of projects stages and stakeholders?	· Homeowners and contractors are the key stakeholders associated with seven of ten key risks. · On-site construction is the key stage at which most of the key risks are concentrated.
		What are the TCs associated with key risks?	TCs related to ten key risks are mainly information costs, negotiation costs, and monitoring costs, and the government is the main bearer of TCs.
Chapter 3	What are the important risks perceived subjectively by different stakeholders in residential energy retrofitting projects in the HSCW zone of China?	What are the differences in risk perception among key stakeholders?	· Government and contractors are concerned with the risks caused by homeowners' poor understanding and cooperation, but homeowners and designers have significantly less concern about these risks. · Compared to government and contractors, homeowners have significantly more concern about the risks of contractors' opportunistic behaviours and material quality. · Homeowners express significantly more concern about the risk of maintenance than the other three groups. · Designers have significantly more concern about risks relevant to drawing design schemes than the other three groups.
		What are the reasons causing the diverse perception of different risks?	Based on the analysis of the tendency and barriers of risk perception, the difference in risk perception is considered to result from responsibility, interest, and trust.
		What are the influences of different levels of risk perception on stakeholder's behaviours?	High levels of risk perception can motivate stakeholders' proactive behaviours of risk mitigation, but risk-source-related stakeholder groups are more likely to take effective measures for risk mitigation.

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TABLE 6.1 Summary of Answers to the Research Questions

	Key question	Sub-question for each key question	Answers to the research questions
Chapter 4	What is the retrofitting information that contributes to the improvement of homeowners' cooperation in residential building energy retrofits in the HSCW zone of China?	What is information having a significant influence on the level of homeowners' cooperation?	· Retrofitting benefits and positive information about retrofitting services have a significant positive influence on homeowners' cooperation. · Increased building information indirectly hinders homeowners' cooperation. · In the case of the high credibility of social contacts, technology information plays a significant negative role in homeowners' cooperation.
		What is the role of risk perception in the relationships between information and homeowners' cooperation?	· Risk perception plays a significant mediation role in the relationship between building information and homeowners' cooperation. · Risk perception has a significant mediating influence on the relationship between positive information about retrofitting service and homeowners' cooperation.
		What role does the source of information play?	· All significant relationships, except for the direct effects of risk perception and positive retrofitting service, are moderated significantly by information source credibility, and information plays a greater role in the case of high source credibility. · Influenced by the high credibility of social contacts with laypeople, the effects of retrofitting technology information are changed to be 'significant' from 'insignificant'.

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TABLE 6.1 Summary of Answers to the Research Questions

	Key question	Sub-question for each key question	Answers to the research questions
Chapter 5	What are the strategies for mitigating risks of the government-led energy retrofitting projects in the HSCW zone of China?	What are the factors causing the increase in the TCs incurred by risk-related project activities?	· Two asset-specificity factors: the experience in performing risk-related project activities and the maturity in the operation of risk-related project activities · Four types of uncertain environmental factors (including fifteen sub-factors): retrofit complexity and quality, retrofitting market maturity, costs and time restriction, and design basis · One frequency factor: the number of the completed residential energy retrofitting projects in each city
		What are the TCs-related factors affecting the government's performance in various risk-related project activities?	· Immaturity in operation is the most important barrier to the government performing risk-related project activities. · Costs and time restrictions, and immature retrofitting market are also important hindrances. · Retrofit complexity and quality are the most important among all uncertainties, but are a motivator of good government performance.
		What role does the government play in the mitigation of different risks?	· The government should assume the primary responsibility for addressing the risks about homeowners' awareness and cooperation, the competence of technical staff, technical standards, and building quality. · Other project parties, especially contractors, need to be in charge of other risks, and the government is responsible for supervision and guidance.
		What are policy recommendations to mitigate risks?	· Information popularization · Establishment of energy service databases · Exchanges of technology experience · Perfecting building diagnosis before retrofitting · Developing financing diversification · Promoting post-evaluation of retrofitting projects · Encouraging material and personnel certification

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6.2 Exploring the mitigation strategies for the risks in residential energy retrofitting projects

This section summarizes the main findings of the four core chapters and answers the corresponding research questions. Chapter 1 presents the risk management process, including risk identification, assessment, and mitigation, as a conceptual framework for exploring the strategies of risk mitigation in energy retrofitting of residential buildings in the HSCW zone of China. Meanwhile, TCT is incorporated into this framework, contributing to risk identification and risk mitigation. Based on risk identification, Chapters 2 and 3 assess the risks in two aspects of objective risk parameters and subjective risk perception. Chapter 4 and 5 focus on risk mitigation. Chapter 4 pays attention to homeowner-related risks that are the most critical risks. Chapter 5 is conducive to develop mitigation strategies for more risks from the perspective of the government.

6.2.1 What are the key risks hindering the implementation of residential energy retrofitting projects in the HSCW zone of China from the perspective of objective risk assessment?

Through both in-depth interviews with key stakeholders in cases and questionnaire surveys with professional practitioners, the results present that ten key risks are mostly related to homeowners and contractors that occur during the on-site construction. Three of the four top risks impeding project implementation are associated with homeowners, including their low awareness at the early stage and poor cooperation and opportunistic behaviours at the stage of on-site construction. After the homeowners, contractors are the most critical stakeholders relevant to the risks during the on-site construction. Their professional expertise and construction and safety management are the important sources of project risks. In particular, a high significance level on the risk of unqualified contractors comes from its severe impacts rather than the probability of occurrence.

Information, negotiation, and monitoring costs are the main TCs related to the key risks. Information costs are the most common costs, and government and homeowners are the main bearers. Such costs are incurred by the government's activities of selecting retrofit projects, technical standards, and technical staff.

Homeowners also need to collect information on retrofit merits, the reliability of construction companies, and maintenance. Negotiation costs are associated with homeowner-related risks and arise from persuading homeowners at the early stage and renegotiating for homeowners' requirements beyond the plan during the on-site construction. Monitoring costs are related to the maintenance risk and incurred by monitoring energy-efficient technologies and building maintenance after retrofitting.

6.2.2 What are the important risks perceived subjectively by different stakeholders in residential energy retrofitting projects in the HSCW zone of China?

The results of in-depth interviews and questionnaire surveys with four stakeholder groups reveal that risk perception is diverse among different stakeholders. Stakeholders' risk perception is mainly dependent upon their responsibilities and interests. As the organizer and decision-maker, the government has more concern about the risks affecting the overall enforceability of retrofit projects. Similarly, the risk perception of designers and contractors is also consistent with their roles as service providers, focusing on the risks hindering the fulfilment of their duties, such as insufficient objective information and uncooperative partners. By contrast, homeowners attach more attention to the risks regarding their own interests, such as the quality of materials, the competence of contractors, contractors' work performance, and the safety of the construction site. Through the comparison between qualitative data and quantitative data, the results also confirm that a high level of risk perception can be viewed as a motivator of proactive measures for risk mitigation. Still, the effectiveness of some proactive measures, especially taken by non-risk-source-related stakeholder groups, cannot be ensured due to the limitation of individuals' knowledge and external environment factors.

In terms of some construction-related risks, homeowners have significantly higher levels of risk-perception than other stakeholder groups. As mentioned above, homeowners express much concern about contractors' abilities, material quality, and even the legalization of contractors' actions, which are not recognized by practitioners, especially government and contractors. The government selects contractors through bidding, and tends to believe that contractors take the government-investment projects more seriously. For contractors, the current energy-efficient technologies adopted in most residential energy retrofitting projects in China are relatively traditional and basic, convincing them that their professional expertise is enough to cope with the construction work. A high level of perception about these risks makes homeowners more inclined to safeguard their own interests by making more requests for retrofitting.

6.2.3 What is the retrofitting information that contributes to the improvement of homeowners' cooperation in residential building energy retrofits in the HSCW zone of China?

The questionnaire surveys with homeowners validate three theoretical hypotheses regarding the relationships among retrofitting information, source credibility, risks perception, and homeowners' cooperation. The results reveal the varied roles of different kinds of information in homeowners' cooperation and support the mediation effect of risk perception and the moderation effects of source credibility. Retrofitting benefits and positive information about retrofitting services have directly positive influences on homeowners' cooperation. The indirect effect of service information via risk perception is also significant. Meanwhile, the high credibility of information sources is a prerequisite to these significant effects.

The effects of building information and retrofitting technology information on homeowners' cooperation are diverse in different cases. There is no significant direct connection between building information and homeowners' collaboration. Still, increased building information amplifies homeowners' risk perception due to the poor quality of old residential buildings, hindering their cooperative behaviours. This significantly indirect effect also requires the high credibility of information sources. Similarly, increased technology information does not contribute significantly to homeowners' cooperation. Still, influenced by the high credibility of social contacts with laypeople, the roles of retrofitting technology information are changed to be 'significant' from 'insignificant', which can be attributed to the difficulties of laypeople in understanding technology information.

6.2.4 What are the strategies for mitigating risks of the government-led energy retrofitting projects in the HSCW zone of China?

Based on three transaction determinants of asset specificity, uncertainty, and frequency, the factors affecting the government performing risk-related project activities are identified. This study examines the influences of these factors on government's behavioural intentions towards risk-related activities in terms of different risks, through the questionnaire surveys with the government officials from nine cities. The results reveal the importance of asset specificity and uncertainty to project running and risk mitigation. Immaturity in the operation of project activities is the most important obstacle to the government running projects. Retrofitting complexity and quality is an especially uncertain factor because it can motivate to a large extent the government to perform the risk-related project activities well. Environmental uncertainties regarding costs and time restrictions and immature retrofitting market also need to be valued.

Through survey respondents' views on risk allocation, the results consider the government responsible for mitigating risks about homeowners' awareness and cooperation, the expertise of technical staff, technical standards, and building quality. Immaturity in the operation of project activities and costs and time restrictions can be the lens to develop government strategies for mitigating these risks. Accordingly, the thesis recommends the government disseminate information, build energy service databases, exchange technology experience, enhance building diagnosis, develop financing diversification, and promote project post-evaluation. The results also reveal the role of the government as the supervisor and guide in the mitigation of other important risks regarding on-site construction and post-retrofitting usage. The thesis provides the corresponding recommendations from the perspective of the maturity of the retrofitting market and suggests the government encourage certification of both material and personnel standards.

6.3 Policy recommendations

This thesis conducted an in-depth analysis of risks in the energy retrofitting process to develop mitigation strategies to promote and smoothen its energy retrofitting in the Chinese residential building context. In Chapter 1, the risk management process is presented as a conceptual framework to illustrate how risks are analysed. This process includes risk identification, risk assessment, and risk mitigation. Based on risk identification and assessment in Chapters 2 and 3, Chapters 4 and 5 discuss the mitigation strategies of different risks from the angle of risk occurrence. Chapter 4 focuses on homeowner-related risks that are the most critical risks and aims to improve homeowners' cooperative behaviours through information provision. Given the important role of the government in residential energy retrofitting, Chapter 5 explores the TC-related barriers to government performing risk-related project activities in order to reduce the occurrence of important risks. Through the in-depth exploration of risk mitigation, the following four roots of risk occurrence are reflected: 1) the ignorance of homeowners' actual needs; 2) limited sources of funding; 3) the neglect of retrofitting effects on actual energy savings, and 4) the lack of technical support targeting at residential energy retrofitting. These four points are explained as follows.

6.3.1 The ignorance of homeowners' actual needs

In China, there is a lack of a feedback loop to effectively incorporate homeowners' thinking into the design of retrofitting schemes. Homeowners play a relatively passive role in the implementation process of residential energy retrofitting. Homeowners' decision-making on retrofitting items is limited to a range of options provided by the local government and designers in advance. Still, they are also given certain power of providing feedback to the pre-existing technical plans. Indeed, it has been proved by Vlasova and Gram-Hanssen (2014) that a dialogue between energy advisors and homeowners is necessary to determine the retrofitting technologies. However, as the project organizer, the local government does not provide an effective channel for homeowners to communicate with retrofitting designers. The work team of the local government acts as an intermediary to display the preliminary design scheme in a public platform and transfer homeowners' feedback to the designers. This one-time process of indirect feedback makes it difficult to achieve effective communication between homeowners and designers. Moreover, field surveys show that, it seems that the pre-existing technical plans are seldom questioned or opposed by homeowners

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in this process, which can be attributed to homeowners' limited knowledge about energy retrofitting. The central government has not attached sufficient importance to information dissemination measures (Liu et al., 2020b). Although the Chinese government has made some achievements on residential energy retrofitting (e.g., demonstration projects and pilot projects), it is still difficult for homeowners to acquire the relevant information due to the lack of platforms and activities of information dissemination. The lack of knowledge further increases homeowners' difficulties in understanding the technology schemes, reflecting another shortcoming in the current feedback system. The government does not consider if homeowners can understand these retrofitting technologies when asking homeowners for advice.

The limitation of technology itself is also a barrier to meeting homeowners' needs. Residential energy retrofitting in the same city or even in the same province tends to be standardized. That is, the same and basic energy-saving technologies are adopted to different retrofitting projects. Such standardized technology packages generally only include some outdated technologies, such as the simple replacement of existing equipment. In fact, the central government has encouraged the adoption of new technologies (e.g., renewable energy technologies) to building energy retrofitting in the Energy Conservation Law issued in 1997 and amended in 2007. However, it appears not to be applicable in the sector of residential buildings. Even the central government's technical specification for residential energy retrofitting issued in 2012 considers the building envelope as the only focus of energy retrofitting in the HSCW zone. In addition, although the research and development of energy-saving technologies have also been encouraged in this law, there is no incentive policy for supporting technological innovation in the building sector. Indeed, little is invested in the research and development of technology in the traditional industry, such as construction (Liu et al., 2020a).

The research provides three recommendations for the government in terms of addressing to the need of residents. First, homeowners should be provided with more direct channels to communicate with designers. Moreover, their communication needs to presume that homeowners do not know energy retrofitting to ensure that homeowners can understand the provided retrofit proposals, which is also the standard practice in the Energy Service Company (ESCO) retrofit project (Vlasova and Gram-Hanssen, 2014). Second, the government must develop more channels for information provision. In fact, mass media, such as Internet, TV, and radio, has been recognized by many countries (e.g., the Netherlands, Demark, France, and Italy) as an effective tool to disseminate retrofitting information and knowledge. Third, the government needs to develop subsidies and incentives to encourage the investment in technology innovation of building energy retrofitting. For example, the Dutch government initiated tax deduction schemes to promote innovative environmentally friendly products and technologies.

6.3.2 Limited sources of funding

Heavy dependence on government funds is one of the main limitations of residential energy retrofitting in China. Under the local government-led model, government funding is the most important source of funds for energy retrofitting in practice, especially in the HSCW zone. The Chinese government has recognized the need for homeowners' financial support since residential energy retrofitting was highly promoted. However, how to promote the homeowner's investment in energy retrofitting is not reflected in the current policy. Financial support policies issued by the central government focus on subsidy and reward funds provided for the provincial government. Even the specific share of homeowners' investment in retrofitting projects has not been mentioned in any official documents. In general, the municipal government receives tasks from the provincial government, and is the leading investor, executor, and decision-maker of energy retrofitting projects. In this case, the local government can carry out the retrofitting projects more smoothly, but the retrofitting technologies used are also limited. To complete more projects under limited funds, the local government tends to apply some basic energy-saving technologies, such as installing external insulation layers on external walls and replacing external windows with double-layer thermal insulation windows. Moreover, given the difficulties in persuading homeowners to invest, the local government tends to skip this step when implementing retrofitting projects.

There is a lack of incentive policies targeted at homeowners, and the government needs to explore the measures for attracting homeowners to invest in energy retrofitting. First, the government should provide direct subsidies for those who are willing to invest in the renovation of their homes. The state subsidies have been proved to be an important motivator of homeowners' investment in complicated and expensive retrofits (Friedman et al., 2018). Second, the government is recommended to develop some incentives for financial institutions (e.g., banks) to encourage them to provide a loan at a favourable rate for homeowners. In fact, a higher interest rate than current mortgage rates and high street-secured loans is some of the reasons for the failure of the Green Deal in the UK (Rosenow and Eyre, 2016). On the contrary, Germany proved successful in that the government offers subsidies to financial institutions in exchange for lower interest rates on renovation loans.

6.3.3 The neglect of retrofitting effects on actual energy savings

Some activities and work on ex-post evaluation have been simplified or even neglected by the local government in practice. The national guidance document issued in 2012 has listed the post-retrofitting evaluation as one of the tasks at the final stage of retrofitting projects, and mentions that retrofitting effects need to be evaluated by the third-party testing institution. The central government also issued ***Assessment Standard for Green Retrofitting of Existing Buildings*** in 2016. However, this voluntary standard is rarely adopted in practice (Liu et al., 2020a). Even the work of ex-post evaluation is difficult to be put into practice. The national planning documents generally use the floor area of the projects that have been completed or the number of these projects to measure the completion of retrofitting tasks in a region. In this case, the achievements of the local government in residential energy retrofitting appear to be only related to the quantity of retrofitting projects, further lowering the importance of ex-post evaluation in the implementation process of residential retrofitting projects. It also reflects a phenomenon that the local government pays little attention to the actual energy-saving effects that can be achieved through retrofitting.

The measurement of retrofitting effects also involves the information about building energy consumption before retrofitting. There have not been databases for building energy consumption in China. Some existing data are the study results from research institutions but are only related to specific cities and certain years. For this reason, the central government has made the provisions for the diagnosis work before retrofitting the technical specification. It requires not only to check the building quality, but also to measure the energy consumption for heating and air-conditioning, indoor thermal environment, thermal performance and heat transfer coefficient of the building envelope, etc. However, field surveys show that, the diagnosis work before residential retrofitting seldom rarely includes the calculation of building energy consumption in practice. In the absence of the data before retrofitting, the retrofitting effects cannot be evaluated, even if energy consumption after retrofitting is measured.

The Chinese government needs to issue mandatory regulations on ex-ante and ex-post evaluation of building energy consumption of retrofitting projects. For example, the Netherlands developed Energy Performance Certificates in 2008 as a legal instrument to require homeowners to present this kind of certificate when selling and renting their buildings. In China, the existing assessment standard of building retrofits can be incorporated into a mandatory certification system, contributing to the promotion of ex-post evaluation in energy retrofitting projects. Besides, an energy audit can be an approach to the ex-ante evaluation of building energy consumption. The CEN (European Committee for Standardization) has affirmed the important role of energy audits in obtaining information on building energy consumption and identifying energy-saving opportunities. Some European countries have issued national laws to make energy audits mandatory in building retrofitting projects. Still, the quality of energy audits is not high due to the lack of standard guidelines (Speccher and Bruni, 2012). By contrast, the US does better because ASHRAE (American Association of Heating, Refrigerating and Air Conditioning Engineers) provides the guidelines for energy auditors (Speccher and Bruni, 2012). Based on the experience from Europe and the US, the Chinese government is recommended to encourage the application of energy audits in residential energy retrofitting and develop useful guidelines for energy audits.

6.3.4 The lack of technical support targeted at residential energy retrofitting

The Chinese government has shown enthusiasm for promoting residential energy retrofitting but is not well prepared for the technology adoption. The government tends to apply the existing technology, codes, and standards to the new field like residential energy retrofitting. According to the national-level technical specification for residential energy retrofitting in the HSCW zone, the design schemes of retrofitting projects are made based on the design standard for energy efficiency of new-build housing in this region. As survey participants of this study, designers also reported that they generally regarded these old buildings as new-build buildings when designing energy efficiency schemes. However, they admitted that the technologies adopted in new-build buildings might fail to significantly improve the energy efficiency of old buildings due to the deterioration and aging of these old buildings. In addition, it seems that the government has not given enough importance to professionals in residential energy retrofitting. In practice, the local government rarely considers the particularities of retrofitting projects when selecting designers and contractors, and such selection is usually based on the experience in new-build buildings. Indeed, as mentioned earlier, the retrofitting projects that have been completed so far have generally adopted basic energy-saving technologies based on experience. These traditional technologies are not hard for designers and constructors in the current construction market. Still, under the trend of comprehensive energy retrofitting, a more professional technical team is essential for successful project implementation to reduce project risks caused by insufficient abilities to apply advanced and complex energy-saving technologies.

In China, there is currently a lack of policies to guide the development of retrofitting professionals and the proper use of energy-saving technologies in retrofitting projects. Education and training are conducive to improving personnel work competence and efficiency (Tabassi et al., 2012). Some European countries have recognized the role of training and education in the development of retrofitting professionals. For example, countries such as Austria, France, Germany, the UK, and Spain have developed a sound training system for energy service providers, including seminars, field trips, and courses, in order to provide reliable energy consultants and building workers for the building energy efficiency market. Besides, certification regimes have also been widely used in energy service providers in Europe. For instance, Germany has built a certification system for qualified energy consultants and building workers and created a list of energy service experts that are recognized throughout Europe. Following the European practice, the Chinese government is recommended to combine the training and education of technical professionals with the certification system, promoting talent development and providing criteria for personnel qualification. Similarly, an appropriate benchmark is suggested to be incorporated into the technology innovation mentioned before to ensure the proper adoption of retrofitting technologies.

6.4 Added value of the research

6.4.1 Contributions to scholarly knowledge

As presented in previous chapters, some research studies have already probed the risks in residential energy retrofitting projects. These studies focus on the investment risks from the perspective of the economy, and these risks mainly act on the energy-efficiency gap. However, few of them explored the risks in the whole process of retrofitting projects from the perspective of project management, especially in the Chinese context where risks in energy retrofitting projects have been barely considered by prior studies. Considering the differences in energy-efficient measures between different climatic regions and the slow progress of residential energy retrofitting in the HSCW zone, this thesis thus focuses on an in-depth exploration of risks hindering the implementation of residential energy retrofitting projects in the HSCW zone of China. This study contributes to the body of knowledge by its systematic investigation of risks in retrofitting projects. It identifies systematically important risks existing in the current retrofitting projects and develops a set of strategies to mitigate these risks. This research methodology can be applied to the risk research of residential energy retrofitting in other climatic regions and even renovate buildings for other uses. Four key contributions to theory/knowledge can be identified, as follows.

First, TCT is applied in this thesis to enrich the risk list in the process of project implementation and explore the important factors related to risk causes. The thesis provides a lens of TCs for the risk research to improve the understanding of risk causes, impacts, and the stakeholders associated with risks. TCT is also adopted to probe the barriers to government performing risk-related project activities. It reduces the possibility of risk occurrence from a holistic perspective of the project running and further mitigating risks.

Second, the thesis provides a subjective perspective to assess risks by exploring the risk perception of different stakeholders. It is conducive to the identification of important risks excluded from experts' views. Moreover, by comparing risk perception between different stakeholders, this study enriches the understanding of the causes of risk perception and its role in stakeholders' proactive behaviours of risk mitigation, providing a new viewpoint for risk mitigation.

Third, the thesis systematically analyses the roles of different retrofitting information in motivating homeowners' cooperation in energy retrofitting projects. The inclusion of risk perception and information source credibility contributes to an in-depth understanding of how information influences homeowners' cooperation. It is also an approach to reducing homeowners' risk perception and improving homeowners' participation and cooperation in building renovation.

Fourth, several quantitative methods are incorporated into data analysis in this thesis, demonstrating the availability of these methods in the study fields of risks and building energy retrofitting. The thesis combines risk matrix and Borda voting to rank risks in order of importance. It is conducive to a more intuitive and detailed risk rating by minimizing the number of risk ties. Both exploratory factor analysis (EFA) and artificial neural network (ANN) are adopted to explore the importance of TC-related factors to executing risk-related project activities. EFA is conducted to reduce input variables of ANN to minimize the degree of redundancy. ANN contributes to solving complex and nonlinear multivariate problems.

6.4.2 Contributions to practice

This thesis is conducive to an in-depth understanding of risks in the whole process of residential energy retrofitting projects in the HSCW zone of China. It identifies and assesses the risks existing in the current retrofitting projects and provides a set of strategies for mitigating essential risks. In addition to scholarly contributions, this research study is vital to the practice of residential energy retrofitting. It supports practice in three ways, as follows.

First, project managers can have a comprehensive understanding of project risks through risk identification and risk assessment. This study enables project managers to recognize the priority of the risks and further prioritize resources to cope with the key issues in future retrofitting projects.

Second, this study develops a set of strategies from the government's perspective, contributing to mitigating the risks in government-led residential energy retrofitting projects at the policy level. These strategies will help the government better understand risk causes and guide them to tackle these issues at their source, further promoting the implementation of residential energy retrofitting.

Third, homeowners can benefit from the strategies for risk mitigation developed in this thesis. The strategy for risk mitigation aim to achieve project objectives and promote project success. This study contributes to maximizing homeowners' living quality and housing value in future retrofitting projects.

6.5 Limitations of the study and recommendations for future research

Through the theoretical and empirical analysis, this study conducted an in-depth exploration of risks in the whole process of residential energy retrofitting projects in the HSCW zone of China and developed a set of strategies for mitigating essential risks. Yet, certain limitations can and should be addressed in future research.

First, this thesis provides a holistic picture of retrofitting risks specific for the HSCW zone, but there might be a certain degree of difficulty in generalizing some results to other climatic regions. There are five main building climatic regions in China, and the retrofitting measures are varied in different regions due to the differences in climatic characteristics. Moreover, different provincial governments have diverse targets and policies for residential energy retrofitting. In these cases, there might be different pictures of retrofitting risks in different climatic regions. For future research, risk research can be extended to other regions than the HSCW zone to present a more general picture of retrofitting risks in China.

Second, this thesis mainly discusses the mitigation measures from the perspective of reducing the possibility of risks, but ignores the lens of risk severity. Regardless of information provision or the government's performance in risk-related project activities, it is considered to reduce the possibility of risk occurrence at the source of risks. Although the thesis mentions some proactive risk management behaviours conducted by stakeholders for mitigating risk impacts, this has not been explored in depth. The reduction of risk impacts can be incorporated into risk mitigation strategies in the future in order to avoid or reduce losses caused by the failure of mitigation measures relevant to risk occurrence.

Finally, the thesis probes the strategies for risk mitigation from the behavioural perspective of government and homeowners. Still, it does not make an in-depth exploration of the roles of industry stakeholders in risk mitigation. Given the importance of homeowner-associated risks, this thesis investigates how to motivate homeowners' participation and cooperation through information dissemination. Meanwhile, under the government-led retrofitting model, the thesis explores the mitigation strategies for important risks based on the government's behavioural performance in risk-related project activities. This study also highlights the important roles of industry stakeholders, especially contractors, in the management of some risks. Future studies can explore how to mitigate risk through greater knowledge of the direct behaviours of these industry stakeholders.

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Appendices

APPENDIX A

Chapter 2

TABLE APP.A.1 Profile of interviewees

	Interviewees	Profile
Pilot interview	G1	Office of building energy conservation and technology in the provincial department of housing and urban-rural development
	G2	Officer of building energy conservation and technology in the municipal bureau of urban and rural construction in the provincial capital city
	G3	Officer in the district bureau of housing and urban-rural development
Case 1	G4	Officer of property management in the municipal commission of housing and urban-rural development
	G5	Officer of chief engineers in the municipal commission of housing and urban-rural development
	G6	Officer of renovation for old residential buildings in the district bureau of housing and urban-rural development
	C1	Chief manager for on-site construction
	C2	On-site construction manager for doors and windows
	D1	Primary member in design team
	H1	Homeowner representative
	H2	Homeowner representative
Case 2	G7	Officer of property management in the municipal real estate bureau
	G8	Officer of construction industry centre in the municipal commission of housing and urban-rural development
	C1	Chief manager for on-site construction
	D1	Primary member in design team
	H1	Homeowner representative
Case 3	G9	Officer of sub-district office
	G10	Officer in the district bureau of housing and urban-rural development
	C1	Chief manager for on-site construction
	D1	Chief designer
	D2	Primary member in design team
	H1	Homeowner representative

Note: G = Government, H = Homeowners, C = Contractors, D = Designers.

TABLE APP.A.2 Descriptions for risks

Risks	Descriptions
R1:Frequent change in demolition policies	It is uncertain if the residential quarters within the scope of the plan will be demolished in the next five years.
R2:Uncertainty on property right and occupancy	It is difficult to connect and communicate with homeowners due to complex property rights and a high vacancy rate.
R3:Lack of awareness of energy efficiency retrofitting	Homeowners are reluctant to renovate their home.
R4:Lack of government departments' coordination and support	Local government departments have a poor performance in coordinating the work related to water, electricity and gas.
R5:Insufficient funds available	Retrofitting costs are very large, but there are only limited government budgets.
R6:Insufficient information regarding the buildings	As-built drawings of old residential buildings cannot be provided so that there is a lack of complete building information.
R7:Uncertainty on the on-site conditions	The on-site environment is complicated and some conditions cannot be considered in schemes design.
R8:Lack of technical staff with specific expertise	Due to the lack of experience, designers fail to fuse the thermal insulation materials with old walls and roofs.
R9:Lack of appropriate technical standards	The current guidelines and standards cannot be applied to practical retrofit projects.
R10:Unqualified building materials	Some building materials cannot meet the requirements because of the lack of transparency in the information of energy-saving materials.
R11:Adverse selection	Contractors hide intentionally some information so that the bidding inviters cannot evaluate tenderers' real abilities.
R12:Lack of construction skills	Construction workers lack the experience and technical ability in the retrofitting of old residential buildings.
R13:Moral hazard	Contractors do not comply with design schemes on purpose.
R14:Poor quality of old residential buildings themselves	Old residential buildings are constructed many years ago so that there are some quality problems in walls and roofs.
R15:Poor construction management	Managers lack the experience in the management of retrofit projects, leading to poor performance in on-site management and the coordination of construction work.
R16:Poor safety management	The on-site construction is difficult and the construction of exterior walls and roofs is at high risk.
R17: Poor performance in cooperation	Different parties do not coordinate and cooperate tightly.
R18:Opportunistic renegotiation	During the on-site construction, some homeowners put unreasonable demands on retrofitting schemes or claim for unreasonable compensation.
R19:Measurement problems	Homeowners have an inaccurate understanding of acceptance criteria, leading to their dissatisfaction with project deliverables.
R20:Inadequate maintenance	Homeowners use inappropriately the post-retrofit homes, causing the damage of insulation.
R21:Difficulties in post-retrofit repair	If water seepage happens on the wall, it is hard for maintenance crews to pinpoint the area of water seepage.

TABLE APP.A.3 Skewness and kurtosis provided by SPSS

	Probability						Impact					
	Skewness			Kurtosis			Skewness			Kurtosis		
	Statistic	Std. Error	Z-score	Statistic	Std. Error	Z-score	Statistic	Std. Error	Z-score	Statistic	Std. Error	Z-score
R1	0,228	0,293	0,778	-0,807	0,578	-1,396	0,051	0,293	0,175	-1,132	0,578	-1,959
R2	0,028	0,293	0,096	0,704	0,578	1,218	0,564	0,293	1,925	0,510	0,578	0,882
R3	-0,312	0,293	-1,065	-0,753	0,578	-1,303	-0,317	0,293	-1,082	-1,090	0,578	-1,886
R4	-0,011	0,293	-0,038	-0,566	0,578	-0,979	0,338	0,293	1,154	-0,278	0,578	-0,481
R5	-0,063	0,293	-0,215	-0,705	0,578	-1,220	-0,033	0,293	-0,113	-0,806	0,578	-1,394
R6	0,312	0,293	1,065	-0,448	0,578	-0,775	0,080	0,293	0,273	-0,868	0,578	-1,502
R7	0,521	0,293	1,778	-0,406	0,578	-0,702	0,557	0,293	1,901	-0,619	0,578	-1,071
R8	0,035	0,293	0,119	-0,891	0,578	-1,542	-0,195	0,293	-0,666	-1,093	0,578	-1,891
R9	0,496	0,293	1,693	-0,250	0,578	-0,433	-0,286	0,293	-0,976	-0,842	0,578	-1,457
R10	0,151	0,293	0,515	-0,385	0,578	-0,666	-0,126	0,293	-0,430	-0,968	0,578	-1,675
R11	0,546	0,293	1,863	-0,202	0,578	-0,349	0,433	0,293	1,478	-0,282	0,578	-0,488
R12	0,272	0,293	0,928	-0,619	0,578	-1,071	-0,002	0,293	-0,007	-0,831	0,578	-1,438
R13	0,284	0,293	0,969	-0,739	0,578	-1,279	0,039	0,293	0,133	-1,120	0,578	-1,938
R14	-0,036	0,293	-0,123	-0,799	0,578	-1,382	0,178	0,293	0,608	-0,813	0,578	-1,407
R15	-0,064	0,293	-0,218	-0,765	0,578	-1,324	0,370	0,293	1,263	-0,623	0,578	-1,078
R16	0,220	0,293	0,751	-0,561	0,578	-0,971	-0,234	0,293	-0,799	-0,832	0,578	-1,439
R17	0,219	0,293	0,747	-1,005	0,578	-1,739	0,043	0,293	0,147	-0,809	0,578	-1,400
R18	0,430	0,293	1,468	-0,863	0,578	-1,493	0,277	0,293	0,945	-0,486	0,578	-0,841
R19	0,387	0,293	1,321	-0,304	0,578	-0,526	0,213	0,293	0,727	-0,737	0,578	-1,275
R20	0,276	0,293	0,942	-0,786	0,578	-1,360	0,315	0,293	1,075	-0,788	0,578	-1,363
R21	-0,110	0,293	-0,375	-0,943	0,578	-1,631	0,183	0,293	0,625	-1,115	0,578	-1,929

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APPENDIX B

Chapter 3

TABLE APP.B.1 Proactive risk mitigation measures taken by stakeholders with high levels of risk concern

	Stakeholder groups with high risk concern	Taking proactive measures for risk mitigation	Details
R1:Frequent change in demolition policies	Government	Yes	“There is a criterion for the selection of renovation projects. These old residential buildings cannot be demolished in the next five years. We consult departments of urban construction and housing construction about the demolition scope. It is better to make sure that these buildings renovated can continue to be used for over ten years…”
R3: Lack of awareness of energy efficiency retrofitting	Government	Yes	“During the project set-up, we provided some information about energy retrofit for residents to enable them to have an understanding of retrofit. It is necessary to communicate with residents, which is the responsibility of the neighbourhood committee and the subdistrict office. During the dissemination of information, we also need to focus on those who are reluctant and indecisive...”
R4: Lack of government departments’ coordination and support	Government	Yes but limited	“Actually, we (the Department of Housing and Urban-Rural Development) are mainly responsible for building renovation, but renovation is also related to water, electricity, and gas that should be handled under the responsibility of other departments. These departments did not actively cooperate with us. In general, if we cannot gain the cooperation of these other departments, we would ask heads of the municipal government and district for help...””Before the implementation of retrofit, we had a workshop and all involved departments are required to attend. We needed to show the construction drawings to these departments to make sure that they can know about the potential impacts of retrofit on water, electricity, and gas...”
R5: Insufficient funds available	Government	Yes but limited	“We encourage homeowners to provide some money for energy efficiency retrofits, but this is simply a suggestion. In reality, homeowners are reluctant to pay for anything. Maybe the minority of homeowners are willing, while most homeowners reject it because of their own interests. ”
R6:Insufficient information regarding the buildings	Designers	Yes	“We acquired the aerial photos from the planning bureau. Moreover, we tried our best to do field work for the measurement of building data such as contour lines of buildings and the size of window and doors.”

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TABLE APP.B.1 Proactive risk mitigation measures taken by stakeholders with high levels of risk concern

	Stakeholder groups with high risk concern	Taking proactive measures for risk mitigation	Details
R7:Uncertainty on the on-site conditions	Designers	Yes but limited	"Prior notice was given on the drawings to highlight the potential obstructs (e.g., cable and gas pipelines on the external walls) during the construction. We also pointed out the possible deviations between design drawings and the on-site practical situations (e.g., hidden pipelines) so that the government could do preparations in advance..."
R9: Lack of appropriate technical standards	Designers	Yes but limited	"Actually we also do not know how to design the retrofitting schemes for old residential buildings due to the lack of requirements so that we can only regard these old buildings as new built buildings…" "For residential buildings, no matter new built buildings or old buildings, we used the same energy-saving design software for modelling and calculation. We viewed the old residential buildings as new built buildings. For example, when designing the insulation of exterior walls, we need to suppose first the original wall surface to be eradicated. Then we redesign the insulation layer and the surface… "
R10: Unqualified building materials	Homeowners	Yes but limited	"We could only observe the materials and touch the surface to make a judgement. We also did not know if these materials are safe and nontoxic. What we knew were dependent on what the contractors said. When having doubts about some materials, we still put forward our opinions and suggested contractors to change it." "We also asked what materials were used, and they told us something about the materials. However, we generally still knew little about it so that we could not be too serious about them. "
R12: Lack of construction skills	Homeowners	No	"We knew little about retrofit construction and these construction workers. We are the lay people, so we could not think about it too much. We could not also do something about it..."

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TABLE APP.B.1 Proactive risk mitigation measures taken by stakeholders with high levels of risk concern

	Stakeholder groups with high risk concern	Taking proactive measures for risk mitigation	Details
R13: Moral hazard	Homeowners	Yes but limited	“During the construction, we could supervise them, and many people crowded around to watch them. Sometimes I also talked with them about mortar and concrete mixing. They told us that these materials were tested. If noticing that they cut corners on retrofit construction, we could call the mayor’s hotline for complaints. However, it was still hard for us to supervise them, because we did not have professional knowledge.”
	Government	Yes	“In terms of construction, there is a set of supervision system, including supervisors, acceptance inspection, and two-year warranty. We also arranged some people to do the field supervision. In general, we went to the construction site every two days, and there was a regular supervision meeting every four days. Homeowners could also feed some problems back to the neighbourhood community, and the neighbourhood community fed these problems back to us. Moreover, the supervision company was selected in the bidding process. Municipal and district departments of quality inspection were also involved in the supervision process. If they found out some problems, they would punish the relevant construction staff, which also could lead these companies to have a bad record…”
	Designers	Yes but limited	“During the construction, we went to do the on-site supervision to check if the construction was conducted according to our design requirements, such as the fixation of insulation walls, external walls and the original walls. However, it was also impossible for us to be always there for the follow-up supervision…”
R14: Poor quality of old residential buildings themselves	Homeowners	Yes but limited	“Before the implementation of retrofit, some professionals came here for quality inspection. During this period, we also asked some questions about building quality to them. Beyond that, we could do nothing. After all, we were the lay people and could not so something about it.”
R16: Poor safety management	Homeowners	Yes	“We paid more attention to our own safety, and also remind others to be careful. For example, when the construction workers were building the scaffold, we reminded the neighbours who was passing by the scaffold to take care.”
	Contractors	Yes	“We erected some barriers around the construction site to prevent residents from approaching the dangerous areas. We also kept up with garbage collection, and always reminded residents to pay attention to their safety. In terms of our own safety, we always supervise the construction workers to wear safety helmets and to fasten safety belts.”

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TABLE APP.B.1 Proactive risk mitigation measures taken by stakeholders with high levels of risk concern

	Stakeholder groups with high risk concern	Taking proactive measures for risk mitigation	Details
R17: Poor performance in cooperation	Government	Yes	"During the design process, we did the field survey in order to respect the will of people. If we did it very well, it would be possible to make the conflicts during the construction less and to make the alteration less. ""The demolishment of illegal constructions was based on the aerials photos in both 1982 and 1996. These photos could be the evidence to enable us to require homeowners to cooperate on the removal of illegal constructions. ""We had some rules and regulars for the prevention of conflicts. For example, we had a mechanism for on-site compromise, and someone was put in charge of some conflicts. There was a billboard on which homeowners could be informed of retrofit contents, parties participating in retrofit projects, the personnel in charge of quality control, and design schemes. "
	Contractors	Yes but limited	"We usually informed homeowners of construction conditions to encourage their cooperation. We paid more attention to our own attitudes and language when communicating with homeowners in order to avoid unnecessary quarrel. We also asked subdistrict office and neighbourhood community for coordination."
R18: Opportunistic renegotiation	Government	Yes but limited	"In the previous projects, we experienced many unnecessary financial losses. For example, before renovating the roof, we had to remove solar water heaters on it. However, many homeowners used the damage of their heaters as an excuse to ask us for the compensation, and we also did not know whether these heaters had been broken before removing them. As a result, we did view the roof renovation as the universal retrofit items. If there was a need to renovate the roof, we first required the good coordination among neighbours."
	Contractors	Yes but limited	"We tried our best to prevent the unnecessary contacting with homeowners' personnel items. Moreover, before the construction, we needed to check if homeowners' solar water heaters have been broken."
R20: Inadequate maintenance	Homeowners	Yes but limited	"We generally supervise each other, and cherish and protect our own home."
R21:Difficulties in post-retrofit repair	Government	No	"The government promotes building energy efficiency, so there are the insulating layers on the exterior wall of the buildings constructed in the recent years. However, the insulating layers broke apart from the some residential buildings only a few years after they were built. At present the technology of the external thermal insulation wall is not mature in our country…"
	Homeowners	No	"We are not the professionals and know little about it. We cannot do anything in addition to rely on government and construction workers."

APPENDIX C

Chapter 4

TABLE APP.C.1 Means, Standard Deviations, and Correlations among Variables

Variables		M	SD	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1	BI	2.44	0.81																	
2	RB	2.34	0.69	0.22**																
3	RT	2.56	0.72	0.28**	0.14**															
4	RS	2.27	0.66	0.30**	0.20**	0.09														
5	RP	3.60	0.76	0.16**	0.03	0.05	-0.11*													
6	HC	3.51	0.81	-0.02	0.21**	-0.02	0.22**	-0.35**												
7	BI-IS1	2.70	1.08	0.01	0.04	0.08	-0.08	-0.10*	0.06											
8	BI-IS2	3.16	1.10	0.00	0.17**	0.09	-0.01	-0.13**	0.13**	0.69**										
9	BI-IS3	3.39	1.01	-0.03	0.13**	-0.02	-0.08	-0.17**	0.07	0.63**	0.64**									
10	RB-IS1	2.87	1.21	0.11*	0.12*	0.07	0.04	-0.14**	0.11*	0.17**	0.24**	0.21**								
11	RB-IS2	3.38	1.09	0.09	0.13**	-0.01	0.10*	-0.14**	0.10*	0.11*	0.24**	0.16**	0.61**							
12	RB-IS3	3.61	1.02	0.06	0.06	0.08	0.02	-0.10*	0.02	0.13*	0.24**	0.19**	0.59**	0.63**						
13	RT-IS1	2.85	0.92	0.09	-0.05	-0.00	0.02	-0.03	0.10*	0.21**	0.20**	0.14**	0.15**	0.09	0.00					
14	RT-IS2	3.38	0.98	0.03	-0.06	-0.02	-0.02	0.04	0.03	0.22**	0.18**	0.19**	0.15**	0.05	-0.06	0.68**				
15	RT-IS3	3.36	0.94	0.06	0.02	-0.12*	0.04	0.05	0.10*	0.21**	0.19**	0.12*	0.08	0.00	-0.08	0.58**	0.62**			
16	RS-IS1	2.68	1.03	-0.03	-0.06	-0.03	-0.09	-0.22**	-0.01	0.23**	0.18**	0.26**	0.06	0.03	-0.09	0.25**	0.27**	0.16**		
17	RS-IS2	3.35	1.04	0.14**	-0.12*	0.02	-0.08	-0.20**	-0.10	0.15**	0.07	0.15**	0.20**	0.15**	0.03	0.21**	0.24**	0.14**	0.59**	
18	RS-IS3	3.15	0.80	-0.08	-0.14**	0.01	-0.11*	-0.14**	-0.06	0.16**	0.06	0.16**	0.11*	0.06	-0.01	0.23**	0.27**	0.10*	0.61**	0.59**

*Note: N=413. *p<0.05, **p<0.01; Two-tailed test. M=Mean; SD= Standard Deviation; BI=Building information; RB=Retrofitting benefits; RT=Retrofitting technology; RS=Retrofitting service; RP=Risk perception; HC=Homeowners' cooperation; IS1=Social contacts with laypeople; IS2=Expert knowledge/expert advice; IS3=Resources published on a public platform.*

APPENDIX D

Chapter 5

TABLE APP.D.1 Explanations for environmental uncertainty indicators

No.	Uncertainties	Descriptions
U1	Resistance of other cooperation units	Other project parties are reluctant to coordinate project activities.
U2	Resistance of residential community	Personnel in the residential community are reluctant to support energy retrofits and project activities.
U3	Design complexity	Design of energy retrofitting project is complex.
U4	Construction complexity	Construction of energy retrofitting project is complex.
U5	Stability of supportive policies	Policies on promoting and improving energy retrofits of residential buildings are unstable.
U6	Urgency of energy retrofitting missions	Schedules of retrofit missions from superior governments are super tight.
U7	Rigidity of limited time and costs	Construction time and costs restricted by the local government are too strict and not flexible.
U8	Integrity of agreement provision	Homeowners' rights and obligations are not presented completely in the retrofitting agreement with homeowners.
U9	Competence of experts for safety appraisal of buildings	Experts' safety appraisal of old residential buildings before retrofitting is not accurate.
U10	Detectability of building quality	Some authentic quality conditions related to old residential buildings before retrofitting cannot be detected.
U11	Availability to qualified design companies	There are limited designers qualified for energy retrofitting projects.
U12	Ambiguity of energy efficiency standards	The standards of energy efficiency for old residential buildings are not clear.
U13	Competence of experts for drafting standards	Technical standards for energy retrofitting drafted by experts are not feasible in practice.
U14	Abnormality in building material market	Materials as leaving factory cannot be guaranteed to be qualified.
U15	Maturity of material technology	Technology for thermal insulation materials is immature and there is a lack of advanced materials.
U16	Ambiguity of criteria for construction companies	The criteria of selecting construction companies for energy retrofitting of old residential buildings are not clear.
U17	Availability to qualified construction companies	There are limited designers qualified for energy retrofitting projects.

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TABLE APP.D.1 Explanations for environmental uncertainty indicators

No.	Uncertainties	Descriptions
U18	Detectability of construction quality	Some authentic quality conditions related to old residential buildings before retrofitting cannot be detected.
U19	Ambiguity of acceptance criteria	Acceptance criteria for energy retrofits are not clear.
U20	Availability to property management companies	There are limited property management companies who are willing to take over old residential qualities.
U21	Ambiguity of quality warranty responsibilities	Contractors' responsibilities for quality warranty after retrofitting are not clear in construction contracts.

TABLE APP.D.2 Questionnaires for measuring behavioural intentions, asset specificity, and uncertainty

Behavioural intention towards the risk-related project activities	
The government intends to make more efforts on persuading and encouraging homeowners to strengthen their awareness of energy retrofits.	1=strongly disagree, 5=strongly agree
The government intends to make more efforts on the selection of the qualified design company to ensure the competence of designers.	1=strongly disagree, 5=strongly agree
The government intends to make more efforts to develop the appropriate technical standards for energy retrofits.	1=strongly disagree, 5=strongly agree
The government intends to make more efforts to monitor the selection and use of building materials to ensure the quality of building materials.	1=strongly disagree, 5=strongly agree
The government intends to make more efforts on the selection of the qualified construction company to ensure the competence of construction staff.	1=strongly disagree, 5=strongly agree
The government intends to make more efforts to monitor contractors' behaviours for construction quality.	1=strongly disagree, 5=strongly agree
The government intends to make more efforts to test building quality before retrofitting.	1=strongly disagree, 5=strongly agree
The government intends to make more efforts to coordinate and monitor the construction operation to smoothen the site construction.	1=strongly disagree, 5=strongly agree
The government intends to make more efforts to manage and control the construction safety.	1=strongly disagree, 5=strongly agree
The government intends to make more efforts to negotiate with homeowners to motivate their cooperation.	1=strongly disagree, 5=strongly agree
The government intends to make more efforts to maintain the buildings after retrofitting.	1=strongly disagree, 5=strongly agree
The government intends to make more efforts to formulate and perfect the schemes of post-retrofit repair.	1=strongly disagree, 5=strongly agree

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TABLE APP.D.2 Questionnaires for measuring behavioural intentions, asset specificity, and uncertainty

Asset specificity	
Experience in persuading and encouraging homeowners	1= low, 5= high
Maturity in the operation of persuading and encouraging homeowners	1= immature, 5= mature
Experience in selecting the qualified design company	1= low, 5= high
Maturity in the operation of selecting the qualified design company	1= immature, 5= mature
Experience in developing the appropriate technical standards for energy retrofits	1= low, 5= high
Maturity in the operation of developing the appropriate technical standards for energy retrofits	1= immature, 5= mature
Experience in monitoring the selection and use of building materials	1= low, 5= high
Maturity in the operation of monitoring the selection and use of building materials	1= immature, 5= mature
Experience in selecting the qualified design company	1= low, 5= high
Maturity in the operation of selecting the qualified design company	1= immature, 5= mature
Experience in monitoring contractors' behaviours for construction quality	1= low, 5= high
Maturity in the operation of monitoring contractors' behaviours for construction quality	1= immature, 5= mature
Experience in testing building quality before retrofitting	1= low, 5= high
Maturity in the operation of testing building quality before retrofitting	1= immature, 5= mature
Experience in coordinating and monitoring the construction operation	1= low, 5= high
Maturity in the operation of coordinating and monitoring the construction operation	1= immature, 5= mature
Experience in managing and controlling the construction safety	1= low, 5= high
Maturity in the operation of managing and controlling the construction safety	1= immature, 5= mature
Experience in negotiating with homeowners during the construction	1= low, 5= high
Maturity in the operation of negotiating with homeowners during the construction	1= immature, 5= mature
Experience in maintaining the buildings after retrofitting	1= low, 5= high
Maturity in the operation of maintaining the buildings after retrofitting	1= immature, 5= mature
Experience in formulating the schemes of post-retrofit repair	1= low, 5= high
Maturity in the operation of formulating the schemes of post-retrofit repair	1= immature, 5= mature

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TABLE APP.D.2 Questionnaires for measuring behavioural intentions, asset specificity, and uncertainty

Uncertainty	
Resistance of other cooperation units	1= supportive, 5= resistant
Resistance of residential community	1= supportive, 5= resistant
Design complexity	1= simple, 5= complex
Construction complexity	1= simple, 5= complex
Stability of supportive policies	1= stable, 5= volatile
Urgency of energy retrofitting missions	1= urgent, 5= relaxed
Rigidity of limited time and costs	1= flexible, 5= rigid
Integrity of agreement provision	1= competent, 5= incompetent
Competence of experts for safety appraisal of buildings	1= competent, 5= incompetent
Detectability of building quality	1= detectable, 5= undetectable
Availability to qualified design companies	1= available, 5= unavailable
Ambiguity of energy efficiency standards	1= clear, 5= ambiguous
Competence of experts for drafting standards	1= competent, 5= incompetent
Abnormality in building material market	1= normal, 5= abnormal
Maturity of material technology	1= mature, 5= immature
Ambiguity of criteria for construction companies	1= clear, 5= ambiguous
Availability to qualified construction companies	1= available, 5= unavailable
Detectability of construction quality	1= detectable, 5= undetectable
Ambiguity of acceptance criteria	1= clear, 5= ambiguous
Availability to property management companies	1= available, 5= unavailable
Ambiguity of quality warranty responsibilities	1= clear, 5= ambiguous

TABLE APP.D.3 Mean values of environmental uncertainties in China

No.	Uncertainties	Mean	Std. Deviation
U1	Resistance of other cooperation units	2,97	1,033
U2	Resistance of residential community	2,68	1,012
U3	Design complexity	3,32	1,099
U4	Construction complexity	3,38	1,128
U5	Stability of supportive policies	2,83	0,985
U6	Urgency of energy retrofitting missions	3,50	0,858
U7	Rigidity of limited time and costs	3,27	1,058
U8	Integrity of agreement provision	3,20	1,008
U9	Competence of experts for safety appraisal of buildings	2,95	1,038
U10	Detectability of building quality	3,38	1,097
U11	Availability to qualified design companies	3,31	1,207
U12	Ambiguity of energy efficiency standards	3,42	1,003
U13	Competence of experts for drafting standards	2,74	1,045
U14	Abnormality in building material market	3,20	1,074
U15	Maturity of material technology	3,22	1,108
U16	Ambiguity of criteria for construction companies	3,34	1,049
U17	Availability to qualified construction companies	3,33	1,014
U18	Detectability of construction quality	3,35	1,165
U19	Ambiguity of acceptance criteria	3,26	1,045
U20	Availability to property management companies	3,64	0,937
U21	Ambiguity of quality warranty responsibilities	2,90	0,983

TABLE APP.D.4 RMSE, MAPE, R2 values of fitted models

Risk	Hidden layers	RMSE		MAPE		R^2	
		training	testing	training	testing	training	testing
R1	1	0,364	0,337	10,52%	8,64%	0,719	0,783
	2*	**0,350**	**0,340**	**10,05%**	**8,77%**	**0,735**	**0,796**
R2	**1***	**0,399**	**0,398**	**11,33%**	**11,12%**	**0.666**	**0.773**
	2	0,440	0,439	12,85%	10,98%	0.582	0.762
R3	**1***	**0,337**	**0,337**	**9,24%**	**8,52%**	**0,780**	**0.699**
	2	0,426	0,418	12,24%	5,65%	0,61	0,817
R4	1	0,472	0,400	14,41%	16,07%	0,607	-0,219
	2*	**0,461**	**0,346**	**14,27%**	**13,31%**	**0,603**	**0,111**
R5	1	0,332	0,262	10,05%	8,40%	0,773	0,808
	2*	**0,311**	**0,272**	**9,06%**	**8,77%**	**0,799**	**0,800**
R6	**1***	**0,386**	**0,385**	**11,15%**	**10,37%**	**0,688**	**0,649**
	2	0,397	0,396	10,61%	11,99%	0,713	0,466
R7	**1***	**0,378**	**0,336**	**13,28%**	**14,25%**	**0,747**	**0,438**
	2	0,397	0,335	14,63%	13,54%	0,717	0,443
R8	**1***	**0,438**	**0,437**	**12,73%**	**11,81%**	**0,590**	**0,588**
	2	0,519	0,516	16,68%	9,16%	0,389	0,651
R9	**1***	**0,479**	**0,481**	**12,13%**	**10,74%**	**0,534**	**0,416**
	2	0,518	0,520	15,67%	13,37%	0,453	0,339
R10	1	0,476	0,478	20,05%	17,36%	0,568	0,368
	2*	**0,471**	**0,482**	**18,89%**	**15,57%**	**0,570**	**0,504**
R11	**1***	**0,506**	**0,514**	**14,51%**	**13,21%**	**0,469**	**0,653**
	2	0,524	0,544	16,97%	13,98%	0,412	0,668
R12	**1***	**0,500**	**0,477**	**16,56%**	**15,81%**	**0,484**	**0,556**
	2	0,527	0,571	19,19%	15,26%	0,385	0,527

Note: "" means the final model for validating the effects of TC-related factors on government performance in risk-related project activities.*

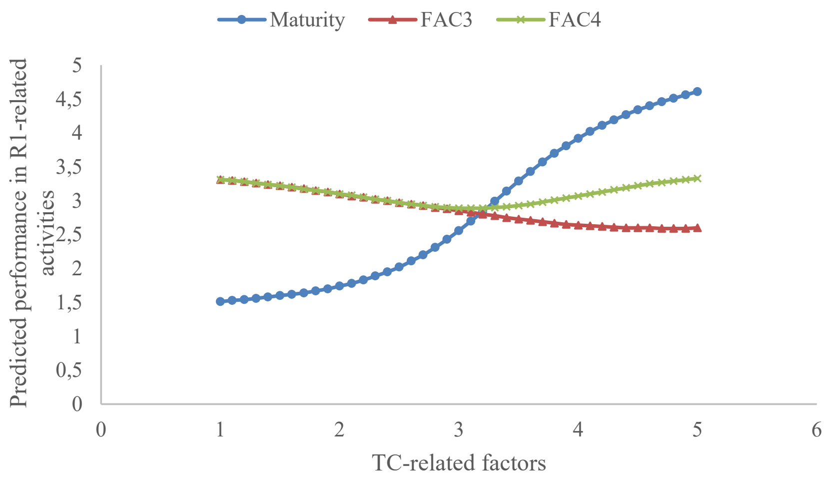

FIG. APP.D.1 Effects of Maturity, FAC3, and FAC4 on the performance in R1-related activities

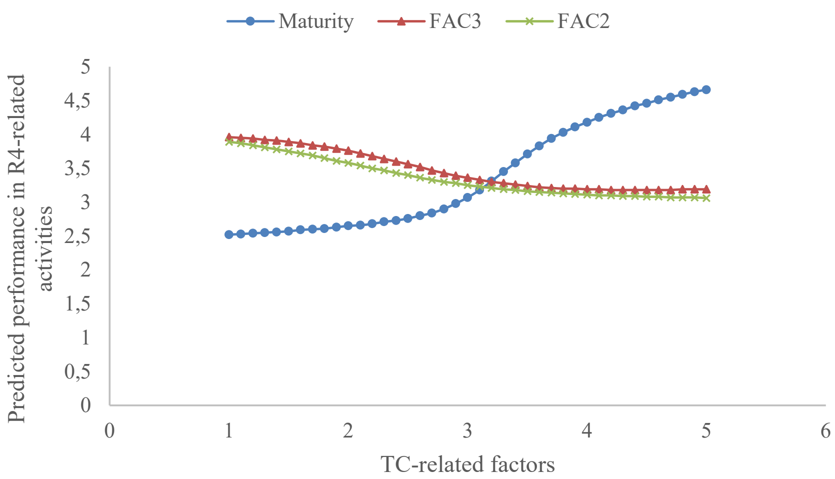

FIG. APP.D.2 Effects of Maturity, FAC3, and FAC2 on the performance in R4-related activities

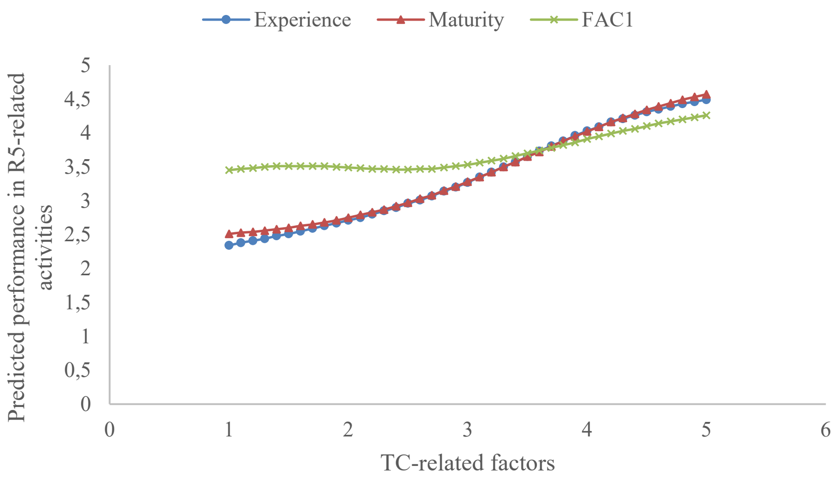

FIG. APP.D.3 Effects of Experience, Maturity, and FAC1 on the performance in R5-related activities

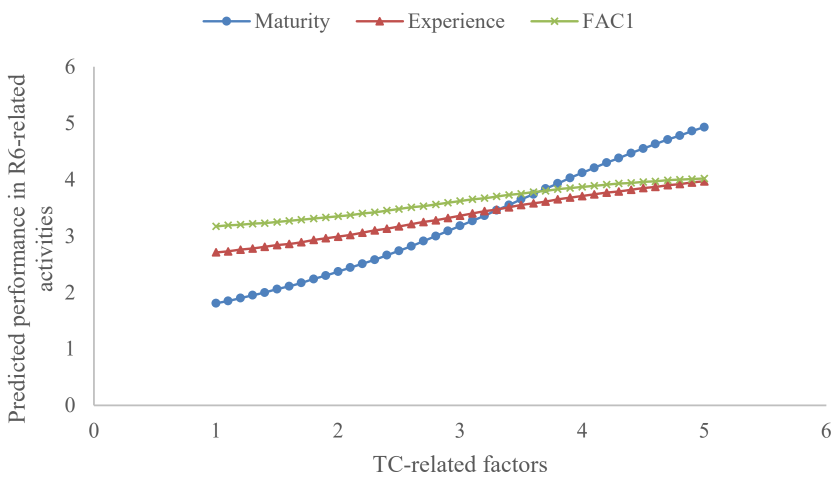

FIG. APP.D.4 Effects of Maturity, Experience, and FAC1 on the performance in R6-related activities

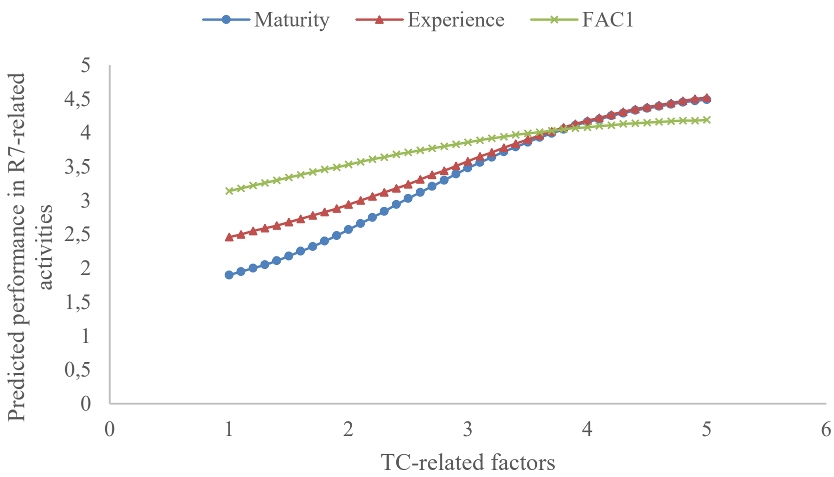

FIG. APP.D.5 Effects of Maturity, Experience, and FAC1 on the performance in R7-related activities

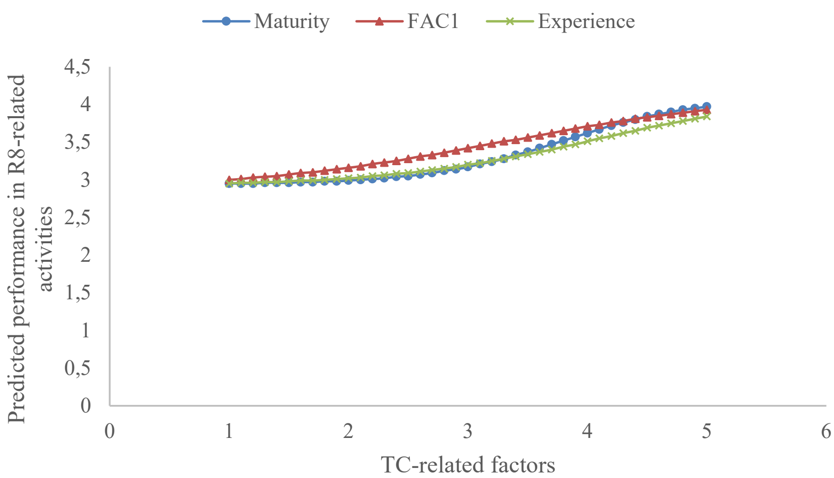

FIG. APP.D.6 Effects of Maturity, FAC1, and Experience on the performance in R8-related activities

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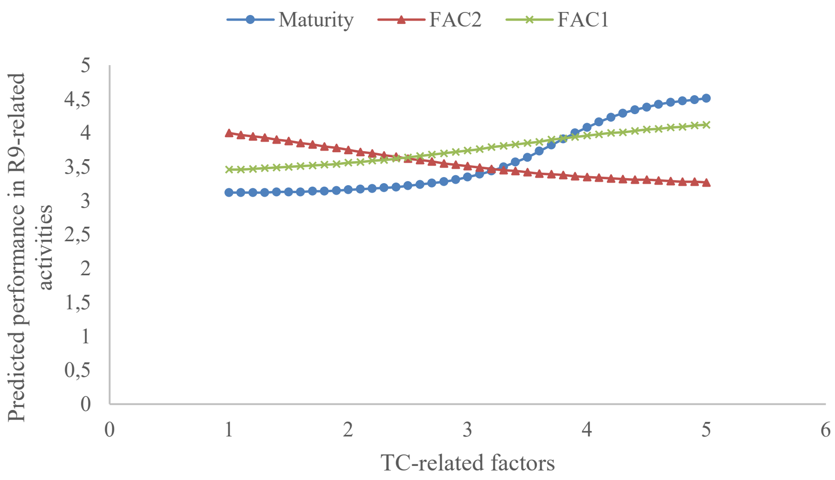

FIG. APP.D.7 Effects of Maturity, FAC2, and FAC1 on the performance in R9-related activities

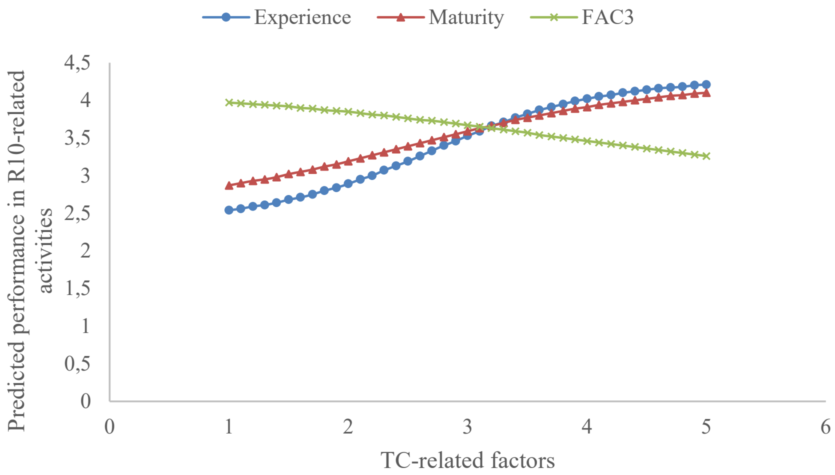

FIG. APP.D.8 Effects of Experience, Maturity, and FAC3 on the performance in R10-related activities

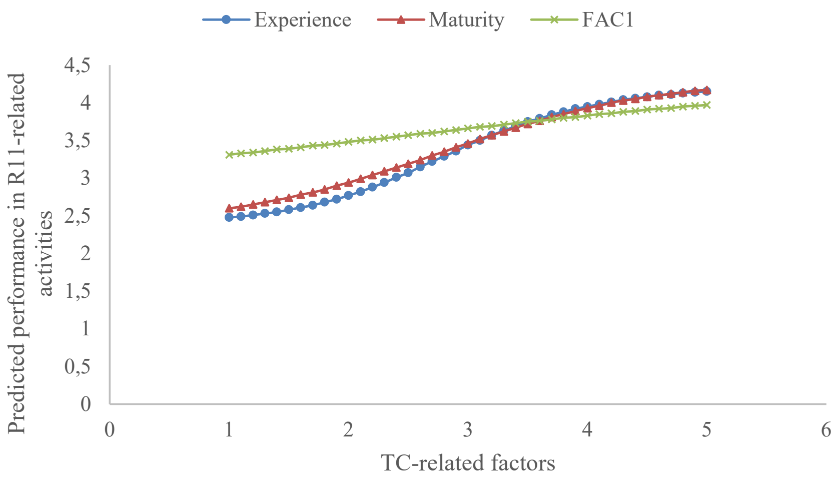

FIG. APP.D.9 Effects of Experience, Maturity, and FAC1 on the performance in R11-related activities

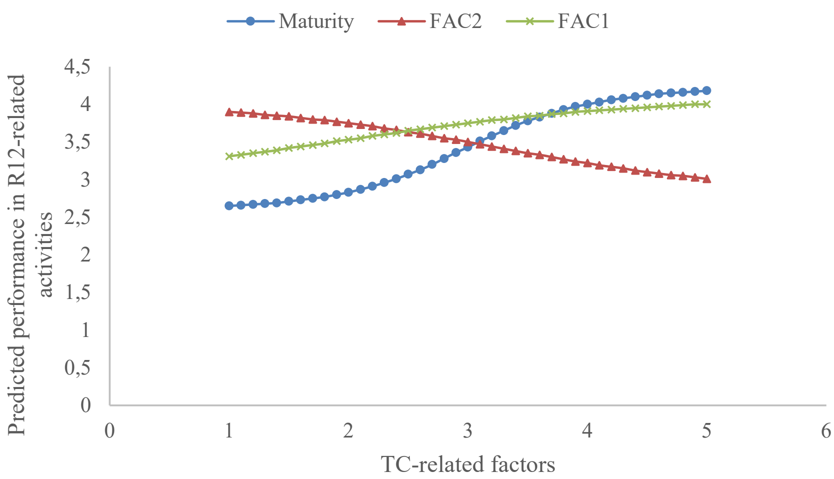

FIG. APP.D.10 Effects of Maturity, FAC2, and FAC1 on the performance in R12-related activities

Curriculum Vitae

Ling Jia was born in November 1989, in Anhui Province, China. In 2011, she obtained her bachelor's degree in Construction Management in Nanjing tech University, Nanjing, China. After that, she obtained the master's degree in Architecture and Civil Engineering in Chongqing University, Chongqing, China. During this period, she learned something about sustainable buildings and tried to do some academic research work. Funded by the scholarship from China Scholarship Council, she started her Ph.D. research in 2016 at the Faculty of Architecture and the Built Environment at Delft University of Technology in the Netherlands. With this PhD project, she has been working on her research work about the risks in residential energy retrofitting projects in China. Meanwhile, she has co-authored several journal articles.

Publications

Journal articles

Jia, L., Qian, Q.K., Meijer, F. and Visscher, H., 2021. How information stimulates homeowners' cooperation in residential building energy retrofits in China. Energy Policy, 157, 112504.

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Mitigating the Risks in Energy Retrofits of Residential Buildings in China

Ling Jia

To speed up residential energy retrofitting in the Hot Summer and Cold Winter(HSCW) zone, the barriers to retrofitting projects need elimination. Energy retrofitting contributes to improving building quality and living comfort, but has not been accepted by the public. It stems from poor project performance in quality, time, costs, etc. The risk is an essential factor hindering such project objectives and project success. Residential energy retrofitting in China is exposed to various risks due to uncertainties regarding finance, organization, coordination, technology, etc. This thesis thus aims to deepen the understanding of risks in the whole process of residential energy retrofitting to smoothen its implementation and develop risk mitigation strategies for the HSCW climate zone of China. The thesis adopts Transaction Costs Theory (TCT) to identify the risks in the whole process of project implementation and assesses the importance of these risks in both objective and subjective aspects. Given the importance of homeowners-related risks and the key role of the government in retrofitting projects, this research develops s series of develop strategies for risk mitigation from the viewpoints of both homeowners and the government. The thesis contributes to the body of knowledge by conducting a systematic exploration of risks in retrofitting projects. In terms of the practical contributions, it does not only enable project managers to recognize the priority of project risks, but also help the government tackle these issues at its source for promotion of residential energy retrofitting.

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